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TECHNIQUES FOR THE COMPUTATION OF WIND, CEILING, AND EXTINCTION--ETC(U)
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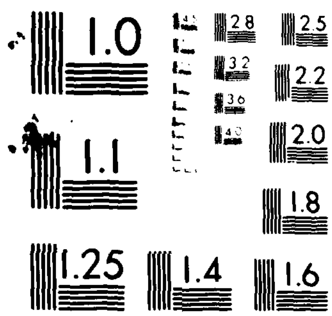

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TECHNIQUES FOR THE COMPUTATION OF WIND, CEILING, AND EXTINCTION COEFFICIENT USING CURRENTLY ACQUIRED RPV DATA

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JULY 1981

By
James L. Cogan

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US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

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Proper deployment and accurate targeting of precision guided munitions depend partly on knowledge of wind velocity, ceiling, and electro-optical extinction in the target area; and knowledge of wind in the target area is crucial for the correct placement of smoke munitions. Wind velocity, ceiling, and volume extinction coefficient in the data silent region near the target may be computed by methods developed in this report using only data currently

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20. ABSTRACT (cont)

acquired by a remotely piloted vehicle of the type now being developed for use by the Army. No new instrumentation is required. The required input consists of flight data and data from an on-board imaging system.

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1. INTRODUCTION

Proper deployment and accurate targeting of precision guided munitions depend partly on knowledge of wind velocity, ceiling, and electro-optical extinction in the target area. Knowledge of wind in the target area is crucial for the correct placement of smoke munitions, since wind velocity near the location where the artillery is deployed may differ considerably from that near the target. The ability to accurately estimate atmospheric characteristics in the target area also should permit the more efficient use of both guided and unguided munitions and thereby reduce the number of rounds needed to accomplish a specific task.

Wind velocity, ceiling, and volume extinction coefficient may be computed by methods (developed in this report) that use only data currently acquired by a remotely piloted vehicle (RPV). No new instrumentation is required; the input consists of flight data and data from an on-board imaging system. Since some of the principal uses of RPV now and in the near future[1] are surveillance of enemy-held territory and target detection and designation, techniques developed herein may be used to describe the above atmospheric variables in the data silent region near the target while the aircraft performs other missions such as surveillance. (See Robinson[2] for a general description of a number of RPV and their instrumentation and Elson[3] for information on the RPV system being developed for the Army.)

The data for the first algorithm for wind velocity, which uses along-wind information, consists of heading, airspeed, and ground speed (or distance flown and time to fly that distance) for two perpendicular courses. The second wind velocity algorithm, which uses crosswind information, requires heading, airspeed, and drift or correction angle for two perpendicular courses. Input for the algorithm for computation of volume extinction coefficient consists of horizontal flight or ground distance, altitude, angles between the vertical and the line of sight (LOS) to the radiating surface, and radiances or equivalent voltages from the radiating surface to the RPV over two separate paths. The ceiling algorithm includes horizontal flight or ground distance, altitude, angle between the flight path and the LOS to the cloudbase, and the angle between the flight path and the LOS to a landmark vertically below the viewed cloudbase. These methods are embodied in computer programs that can be run on a desktop computer. An alternate shorter program is presented for calculation of wind velocity when both headings are known. The computer codes, in BASIC, are shown in the appendix.

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[1]M. H. Crowell, 1980, A Survey of Simulation and Test Results for Assessing RPV Performance in a WBIC Environment, Final Report SPC 615, prepared by Systems Planning Corporation for PMD, Tactical Airborne Remotely Piloted Vehicle/Drone Systems, US Army Aviation R&D Command, Contract DAAK50-80-C-0011, Saint Louis, MO, 50 pp

[2]A. Robinson, 1980, "Battlefield Reconnaissance: Penetrating the Fog of War," Military Tech and Econ, 4(15):33-42

[3]B. M. Elson, 1980, "Mini-RPV Being Developed for Army," Aviation Week and Space Technology, 7 January 1980, pp 2-7

2. ALGORITHMS

The algorithms described in this report are mathematically simple and easy to understand. The manual versions of these procedures require only a simple calculator or trigonometric tables, graph paper, a fine-scaled ruler, and a pencil and paper. A desktop computer able to use BASIC is sufficient to perform the automated versions. The operator need only type in the requested quantities.

2.1 Wind Velocity

2.1.1 First Technique: Distance and Time Input

The input data are (1) airspeed in meters per second along the initial course and the second perpendicular path (X and Y), (2) distance in meters along each path and the associated time in seconds (D_x, T_x and D_y, T_y), and (3) heading (direction to) of each course (Dr_1 and Dr_2). To obtain ground speed (X_g and Y_g), simply divide the distances by the appropriate times ($X_g = D_x/T_x$, $Y_g = D_y/T_y$). Subtracting X from X_g gives the difference C; similarly $Y_g - Y = D$. The windspeed (V) is computed from the formula for the hypotenuse of a right triangle. $V = (C^2 + D^2)^{1/2}$.

The computation of wind direction (Dir) in the desktop computer version requires values of C, D, Dr_1, and Dr_2. If either Dr_1 or Dr_2 is missing (input a 999 for the missing value) two values of Dir are computed, one of which is correct. The correct value may be determined with the aid of other information (for example, a synoptic chart can indicate which of the two values is most likely). When both Dr_1 and Dr_2 are not available, a message is printed saying that no directions were given or computed. A further condition for the computation of direction is whether the orientation of the flight paths is "right" or "left." In the context of this report, the orientation is determined by whether the Y vector is to the right or left of the X vector when facing the direction of flight along the X vector (that is, toward Dr_1). Numerically, "right" occurs when $Dr_2 > Dr_1$ (360° added to Dr_2 if $Dr_2 < 90°$ and $270° \leq Dr_1 < 360°$) and "left" occurs when $Dr_1 > Dr_2$ (360° added to Dr_1 if $Dr_1 < 90°$ and $270° \leq Dr_2 < 360°$).

A "flowchart" (partly in plain English) can provide a better understanding of the intricacies of the first method than a written explanation which could be tedious and somewhat confusing for the reader. Such a chart is presented in figure 1. Figure 2 illustrates the computation of wind velocity for a left orientation when $C > 0$ and $D < 0$, in the case of both Dr_1 and Dr_2 known. These two figures should be used together to gain a basic understanding of the first technique.

The present form of this algorithm uses distance flown and time to fly that distance to compute ground speed. Simple modifications to the program will permit ground speed to be input directly. The input routine would need a slight modification, and the simple computation of ground speed would be eliminated.

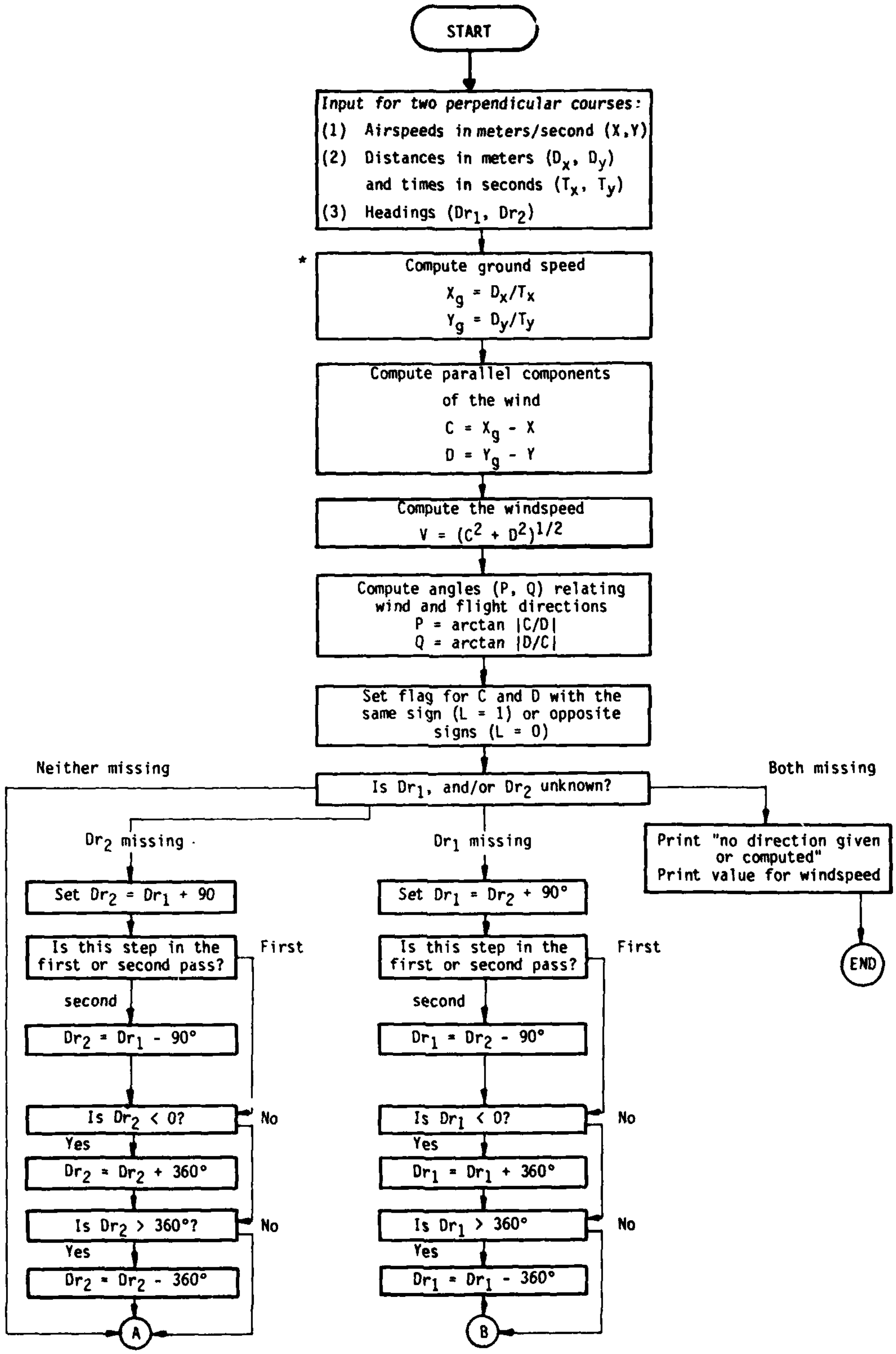

Figure 1. Flowchart of the first technique for computation of wind velocity.

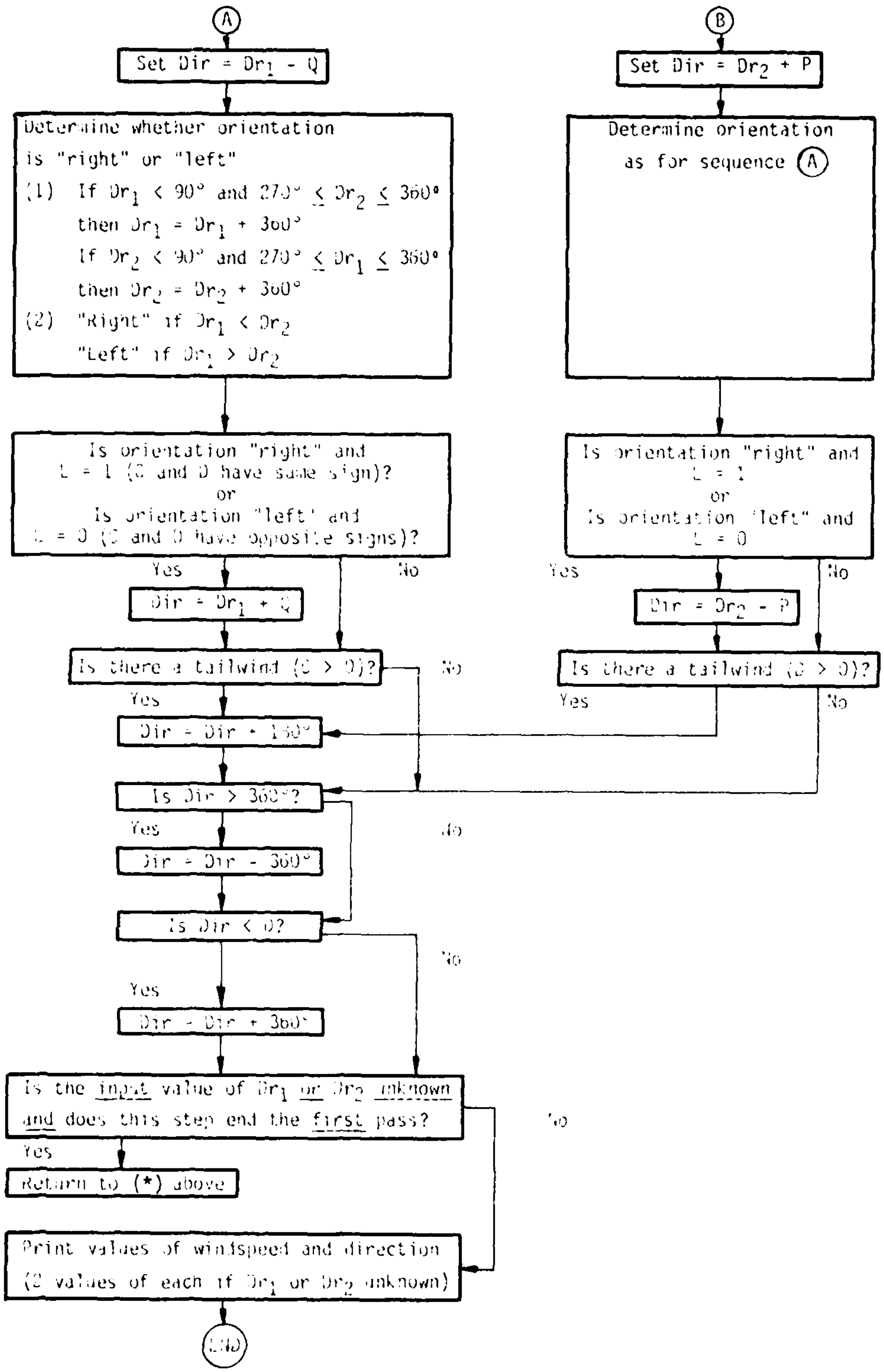

Figure 1 (cont)

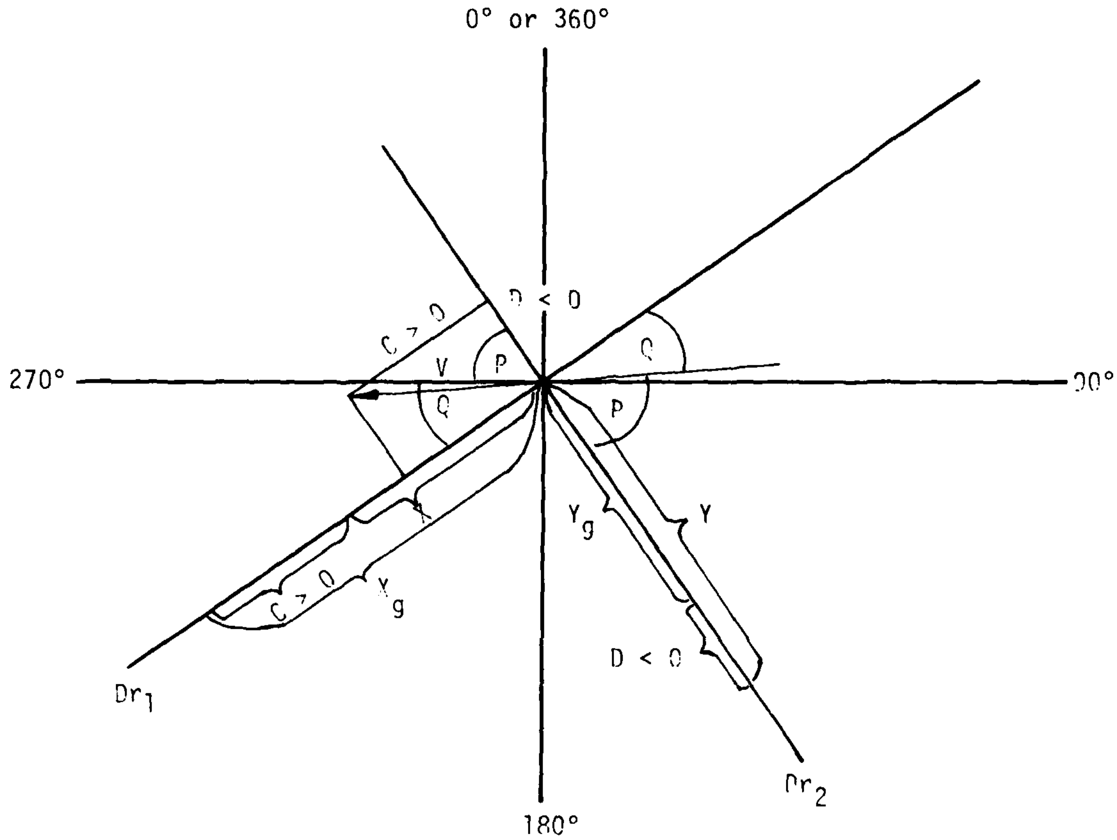

Figure 2. Illustration of the computation of wind velocity by the first algorithm where the orientation is "left," C > 0 and D < 0, and both Dr_1 and Dr_2 are known. X and Y are airspeeds and X_g and Y_g are ground speeds. $C = X_g - X$ and $D = Y_g - Y$. V is the wind vector and P and Q are computed by the arctangents of the absolute values of C/D and D/C, respectively. Dr_1 and Dr_2 are the directions toward which the RPV flies along the X and Y flight paths, respectively. In this example, the wind is blowing from a direction slightly less than 90°.

2.1.2 Second Technique: Drift or Correction Angle Input

The input data are (1) airspeed in meters per second along the two perpendicular courses (X and Y), (2) a flag to indicate whether drift (I = 1) or correction (I = -1) angles are utilized, (3) the drift or correction angles (A and B) in degrees, and (4) the heading of each course (Dr_1 and Dr_2). An angle is considered positive if it describes an arc running to the right of the flight path when facing in the direction of flight. The tangent of the angle times the relevant airspeed gives the crosswind component for each course. $C = X \tan A$, $D = Y \tan B$. The windspeed (V) is computed from the same formula as in the first algorithm; that is $V = (C^2 + D^2)^{1/2}$.

The computation of wind direction (Dir) requires C, D, Dr_1, and Dr_2 as input. If either Dr_1 or Dr_2 is missing (input a 999 for the missing value) two values of Dir are computed, one of which is correct. When both Dr_1 and Dr_2 are missing, a message is printed saying that no directions were given or computed. The orientation, left or right, is determined as in the first method.

A "flowchart" similar to that of figure 1 is presented in figure 3, but for the second method. Figure 4 illustrates the computation of wind velocity for a right orientation where $C > 0$ and $D < 0$, when both Dr_1 and Dr_2 are known. These two figures should be used together to gain a basic understanding of the second technique.

2.1.3 A Shorter Version

A shorter version of the computer program was developed that has about two-thirds the number of statements and storage requirement as the program described in sections 2.1.1 and 2.1.2 of this report. To reduce the number of statements, it was assumed that Dr_1 and Dr_2 would always be known. If either direction is unknown, this program can be run twice with the unknown direction = the known direction $\pm 90°$. (One of the two velocities will be correct.) Consequently, all statements associated with the extra computation required to handle the cases of either Dr_1 or Dr_2 unknown were removed, along with those activated when both directions were missing. A listing of the shorter version is in the appendix along with the listing of the complete version. Figures 2 and 4 illustrate the output from the shorter program.

2.2 Volume Extinction Coefficient

The computer programs for the calculation of volume extinction coefficient require the input of either (1) horizontal flight or ground distance, (2) altitude, (3) or both distance and altitude. If either distance or altitude is unknown, then (4) the angle between the vertical and the slant path (technique A) or (5) the angles between the vertical and the two slant paths (technique B) are input. Finally (6) radiances or (7) equivalent voltages are entered for the respective views of the radiating surface(s).

The equations are derived by first assuming that the vertical distribution and amount of scatterers and absorbers in any vertical column of the same height are constant over the area of interest. This assumption is reasonable to a fair accuracy over small areas of the order of a few tens of square kilometers or less, not in the immediate vicinity of atmospheric "discontinuities" such

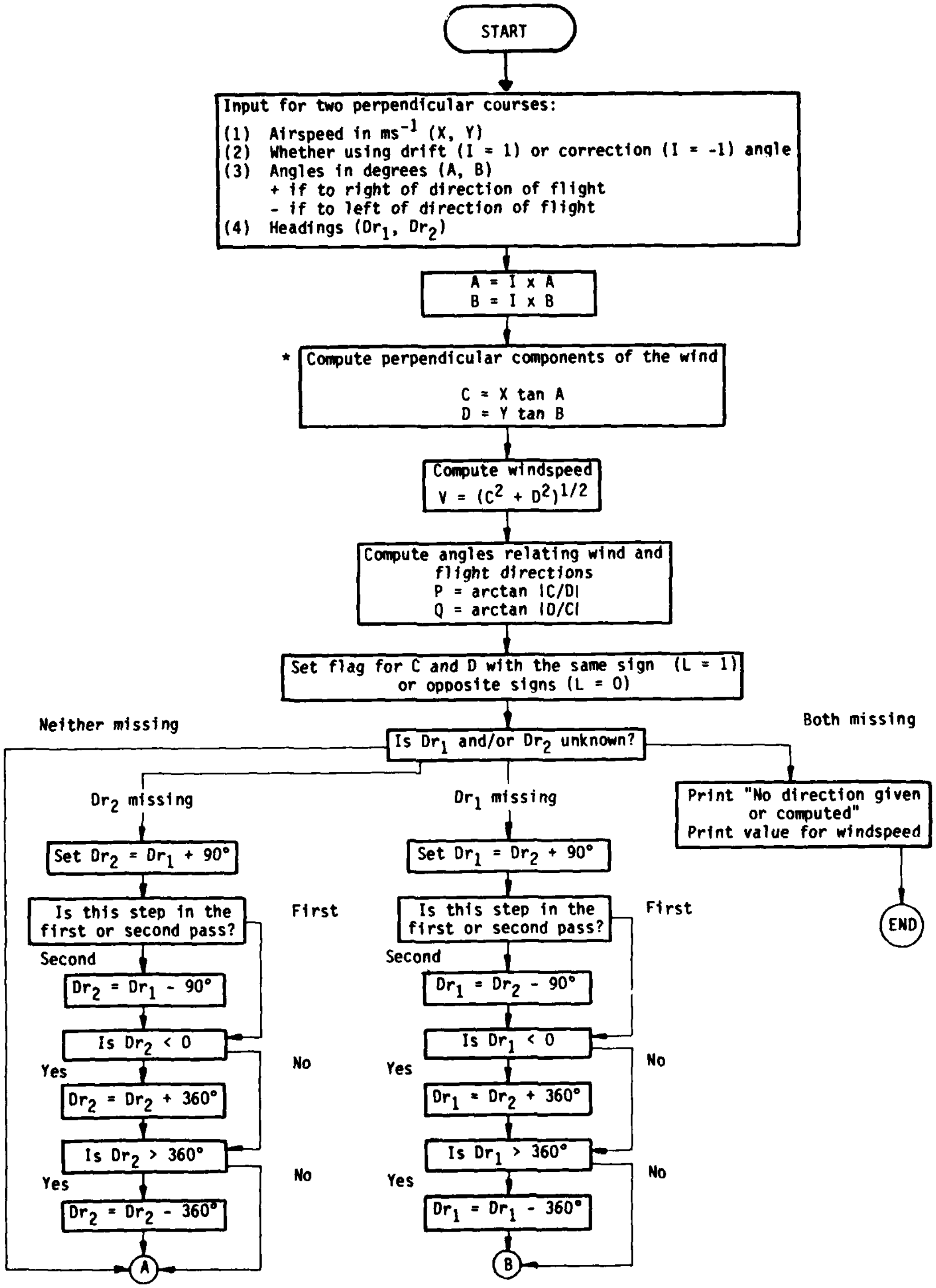

Figure 3. Flowchart of the second technique for the computation of wind velocity.

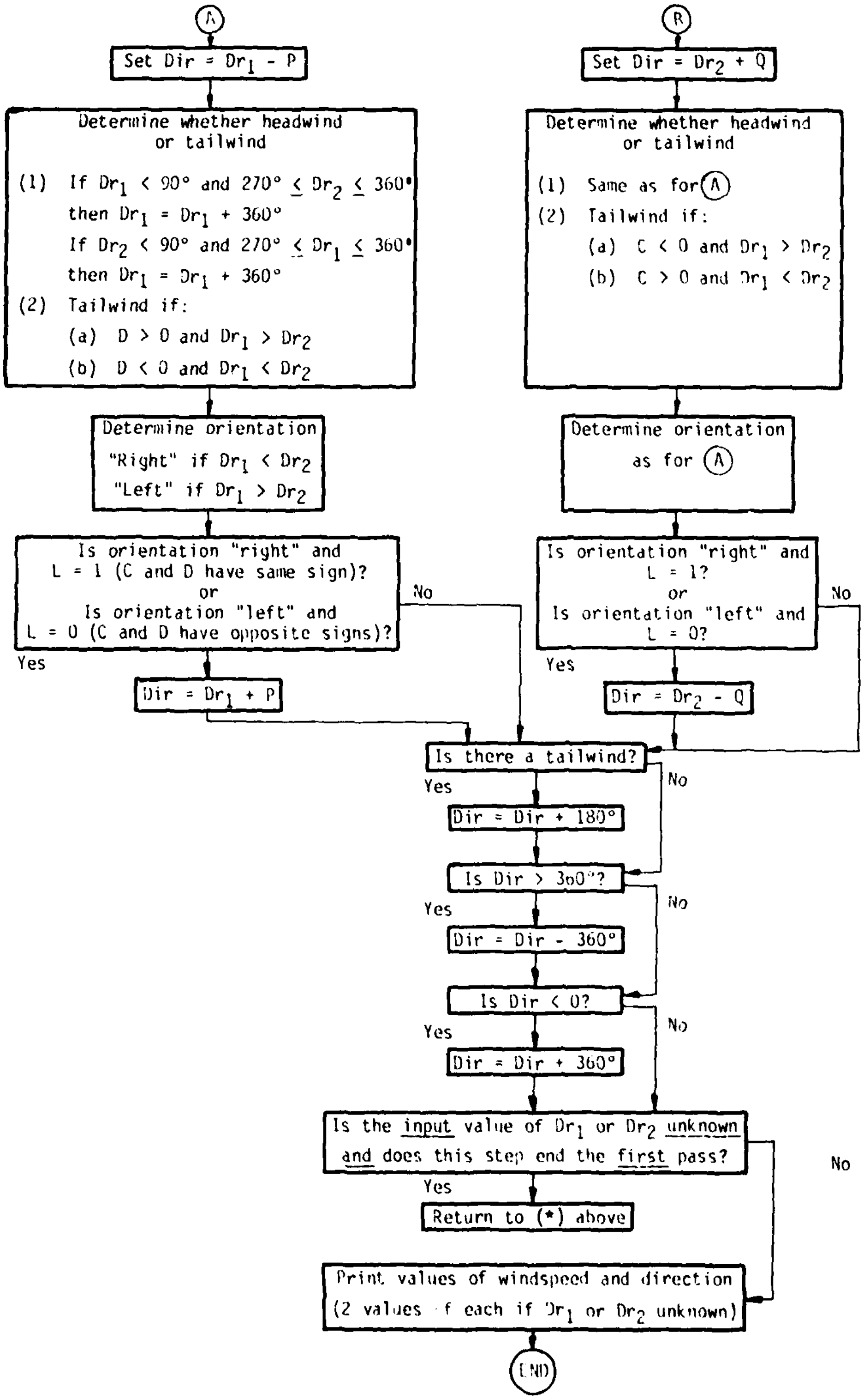

Figure 3 (cont)

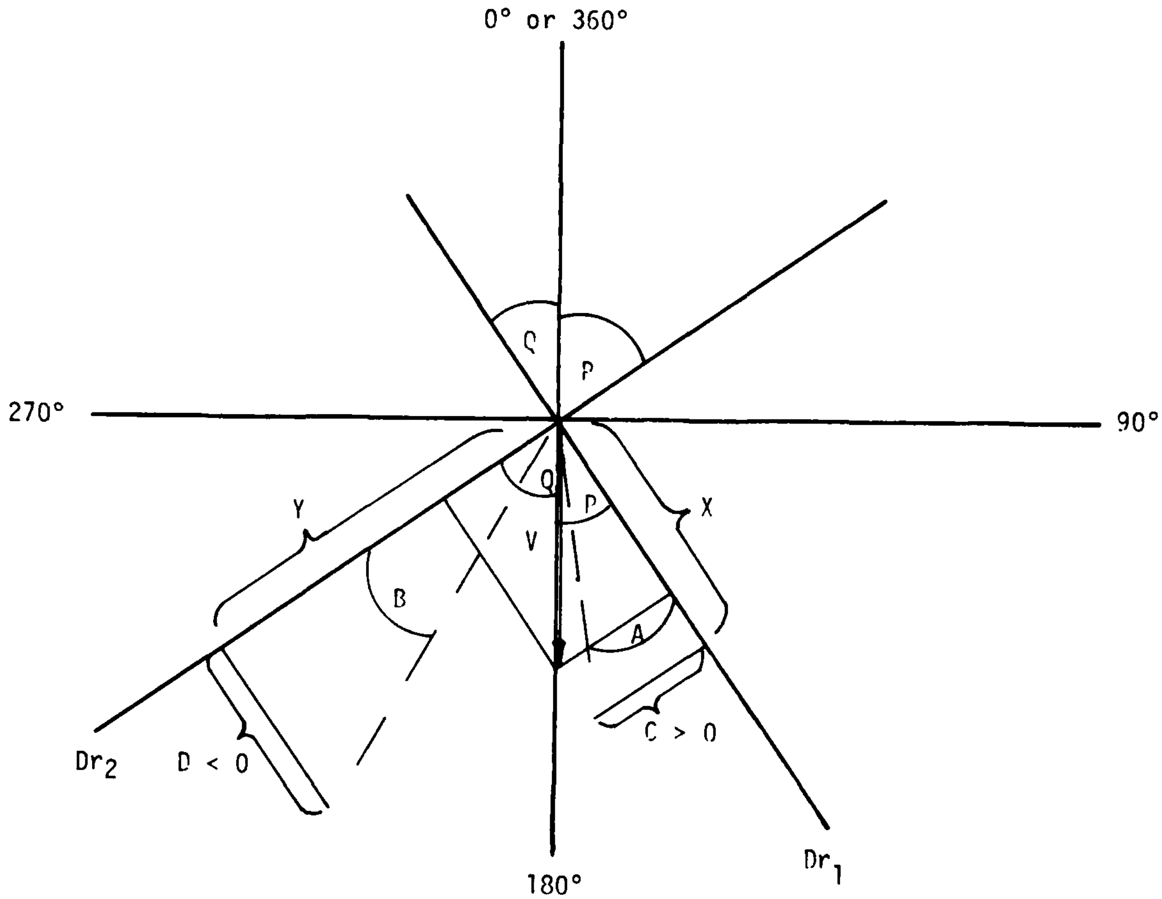

Figure 4. Illustration of the computation of wind velocity by the second algorithm where the orientation is "right," $C > 0$ and $D < 0$, and both Dr_1 and Dr_2 are known. The variables shown are the same as in figure 2 except that A and B are the drift angles (= -correction angles) for the X and Y flight paths, respectively. The crosswind components are $C = X \tan A$ and $B = Y \tan B$. In this example, the wind is from slightly less than 360°.

as a sharp front. Therefore, between a given flight level and the ground, a change in total mass of absorber or scatterer roughly is dependent only on the difference in path length.

Taking the ratio of two radiances from the same source but over different path lengths and using Beer's law, we have:

$$R_2/R_1 = R_0 e^{-k'mZ_2} / R_0 e^{-k'mZ_1}$$

where R = radiance, k' = mass extinction coefficient, m = mass of absorber and scatterer per unit volume, Z_1 and Z_2 are path lengths, and the subscripts 0, 1, 2 refer to values at the source and at the sensor for the two paths, respectively. If we let the volume extinction coefficient (k) = k'm, and we factor out R_0, we have

$$R_2/R_1 = e^{-kZ_2} / e^{-kZ_1}$$

$$= e^{-kZ_2 + kZ_1}$$

$$= e^{k(Z_1 - Z_2)}$$

Taking the logarithm, we have:

$$\ln (R_2/R_1) = k (Z_1 - Z_2)$$

and for k:

$$k = \ln (R_2/R_1)/(Z_1 - Z_2) \tag{1}$$

If the RPV can fly directly over the radiating surface, we can use technique A (see figures 5a and 5b). If overflight is not possible, then use technique B (figure 5c). These techniques are described below; the reader should refer to the appropriate figure (5a, b, or c) in the following descriptions.

2.2.1 Technique A: Overflight of Target

Here we assume overflight is possible. The RPV observes two surfaces of closely similar properties such as different regions of a lake with a very nearly uniform surface temperature, or it looks at the same surface, once vertically and again along a slant path.

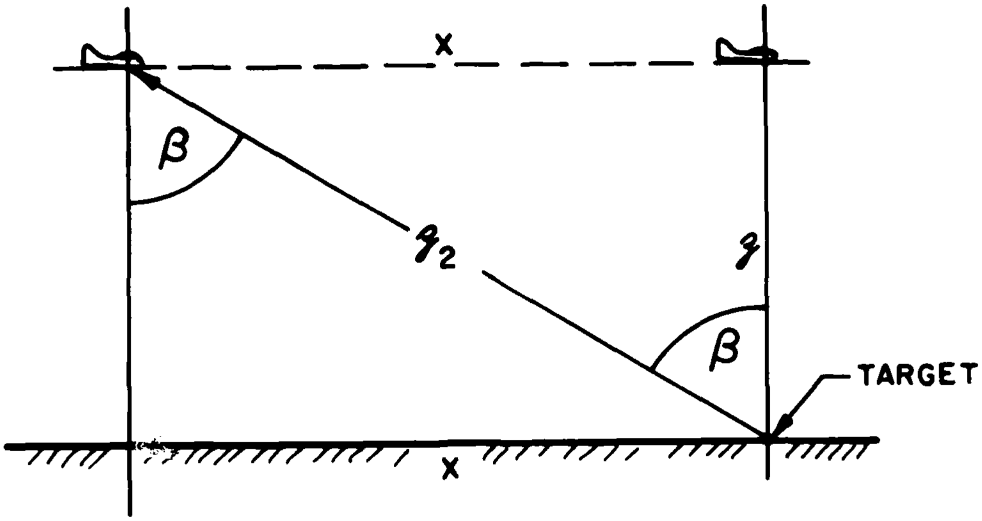

Figure 5a. The geometry for finding the volume extinction coefficient ($k = k'm$) by viewing the same target. (k' = mass extinction coefficient, m = mass of absorber and scatter per unit distance.) x = ground or horizontal distance, β = angle between vertical and line of sight to target, and Z and Z_2 are the vertical and slant paths.

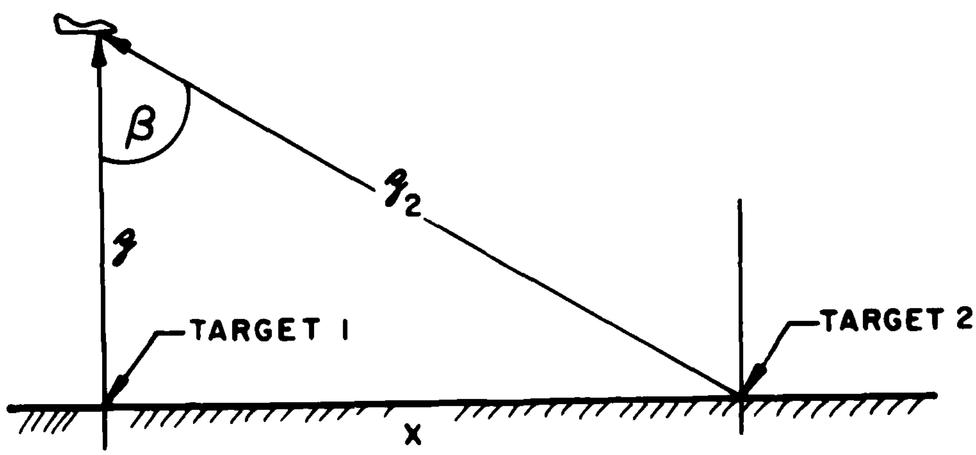

Figure 5b. Finding k by viewing two closely similar targets. Variables are as in 5a.

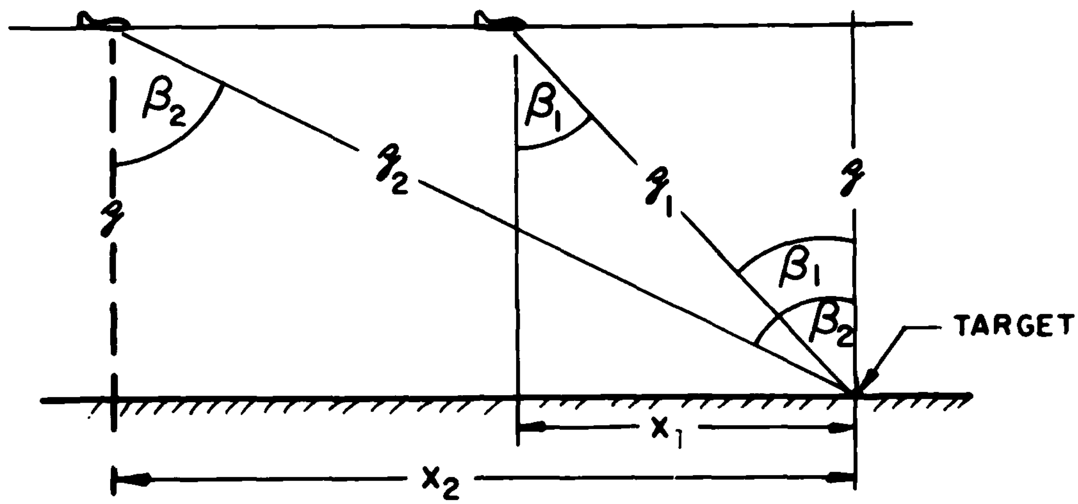

Figure 5c. Finding k by viewing the same target along different slant paths (different angles, both > 0°). Here Z = altitude, Z_1 and Z_2 = slant paths, R_1 and R_2 = respective radiances, β_1 and β_2 = angles between the line of sight to the target and the vertical, and X_1 X_2 are horizontal distances along the ground or flight path.

Referring to figures 5a and b, we see that X = distance along the ground, $Z = Z_1$ = altitude (vertical path), Z_2 = slant path, and β = angle between the vertical and the slant path.

a. If X and Z are known but not β, then

$$\beta = \text{arctangent } (X/Z)$$

and $Z_2 = Z/\cos\beta$.

b. If Z and β are known but not X, then as in a

$$Z_2 = Z/\cos\beta.$$

c. If X and β are known but not Z, then

$$Z_2 = X/\sin\beta$$

and $Z = X/\tan\beta$

Using equation (1) and the above geometrical relationships, we have for the first two cases (a, b):

$$k = \ln (R_1/R_2)/Z(1 - 1/\cos\beta) \tag{2}$$

and for the third case (c)

$$k = \ln (R_2/R_1)/X(1/\tan\beta - 1/\sin\beta) \tag{3}$$

2.2.2 Technique B: Standoff from Target

Here we assume overflight is not possible. The RPV views the same surface from two different angles (neither path vertical as in figure 5c) or views two closely similar surfaces (no figure shown).

Referring to figure 5c, we see that X_1 and X_2 = horizontal distances along the flight path or the ground, Z = altitude, Z_1 and Z_2 are slant paths, and β_1 and β_2 are the respective angles between Z_1 and Z_2 and the vertical. Therefore:

d. If X_1, X_2 and Z are known but not β_1, β_2, then

$$\beta_1 = \text{arctangent } (X_1/Z),\ \beta_2 = \text{arctangent } (X_2/Z)$$

and $Z_1 = Z/\cos\beta_1$, $Z_2 = Z/\cos\beta_2$

e. If Z and β_1, β_2 are known but not X_1, X_2, then as in d

$$Z_1 = Z/\cos\beta_1,\ Z = Z/\cos\beta_2$$

f. If X_1, X_2 and β_1, β_2 are known* but not Z, then

$$Z_1 = X_1/\sin\beta_1,\ Z_2 = X_2/\sin\beta_2$$
$$\text{and } Z = X_1/\tan\beta_1 = X_2/\tan\beta_2$$

Using equation (1) and the above geometrical relationships, we have for cases d and e:

$$k = \ln(R_2/R_1)/Z(1/\cos\beta_1 - 1/\cos\beta_2) \quad (4)$$

and for case f:

$$k = \ln(R_2/R_1)/(X_1/\sin\beta_1 - X_2/\sin\beta_2) \quad (5)$$

However, for $\beta_1 \to 0$ (see figure 5c) equation (5) fails. To avoid this problem, replace $X_1/\sin\beta_1$ with Z (= $X_2/\tan\beta_2$) for small values of β_1 (= several degrees or less). Therefore, in place of equation (5) use:

$$k = \ln(R_2/R_1)/X_2(1/\tan\beta_2 - 1/\sin\beta_2) \quad (6)$$

Note that equations (6) and (3) are the same, where $X_2 = X$ and $\beta_2 = \beta$ (compare figures 5a and 5c).

2.2.3 Computation of Radiance from Voltage

Modifications of the two techniques were developed where radiance is not input directly, but is computed from voltages. Commonly, sensors use devices that transform received energy into voltages, which in turn are converted into radiances by the means of some algorithm. Although the form of the conversion algorithm may differ from one sensor to another (for example, linear or quadratic), a simple linear form was used here only to indicate how such equations would fit into the techniques described in this report. The equations have the form R = a + bV where R = radiance, V = voltage, and a and b are constants determined empirically during calibration. It is assumed that one voltage is produced for each of the two views of the radiating surface or target, yielding the two required radiances.

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*These computations may be performed if either β_1 or β_2 is known. For example, if X_1 and β_1 are known, we can compute Z_1 and Z. Having Z and X_2, we can then calculate β_2.

2.2.4 Computer Programs

Four "flowcharts" were constructed to enable the reader to understand the computer programs more easily and to avoid the possible confusion an entirely written explanation would cause. The reader should refer to figure 5 when viewing these flowcharts. Figure 6 shows the chart for technique A, where the RPV can overfly the target (= radiating surface) and radiances are input. Figure 7 presents the chart for technique A when voltages are input. Figure 7 differs from figure 6 in the substitution of the voltage input and conversion algorithm in place of the radiance input statement. Figure 8 has the flowchart for technique B, where the RPV cannot overfly the target and radiances are input. Figure 9 illustrates the difference in the flowchart for technique B when voltage input replaces radiance input; the entire flowchart is not shown. The programs for both techniques are presented in the appendix.

2.3 Ceiling

Ceiling (c) may be computed by using simple geometry and data from an RPV carrying a movable sensor active in any imaging wavelength region. The required input includes (1) upward elevation angle which is the angle between the flight path and the LOS to cloudbase, and either (2) horizontal flight or ground distance, (3) altitude, or (4) both altitude and distance. If only altitude or distance is known, then input (5) the depression angle which is the angle between the flight path and the LOS to a landmark vertically below the view of the cloudbase.

Referring to figure 10, we have for the ceiling

$$c = h + Z$$

where Z = altitude and h = vertical distance from flight level to cloudbase. Furthermore, $h = X\tan\beta$, where X = horizontal flight or ground distance and β = upward elevation angle. Substituting for h, we have for the case of X and Z known:

$$c = Z + X\tan\beta \ . \qquad (7)$$

If X is known but not Z, we have for Z

$$Z = X\tan\alpha \ ,$$

where α = depression angle. Using equation (7) and substituting for Z, we have for c

$$c = X\tan\alpha + X\tan\beta$$

$$= X(\tan\alpha + \tan\beta) \ .$$

If Z is known but not X, we have for X

$$X = Z \operatorname{ctn}\alpha$$

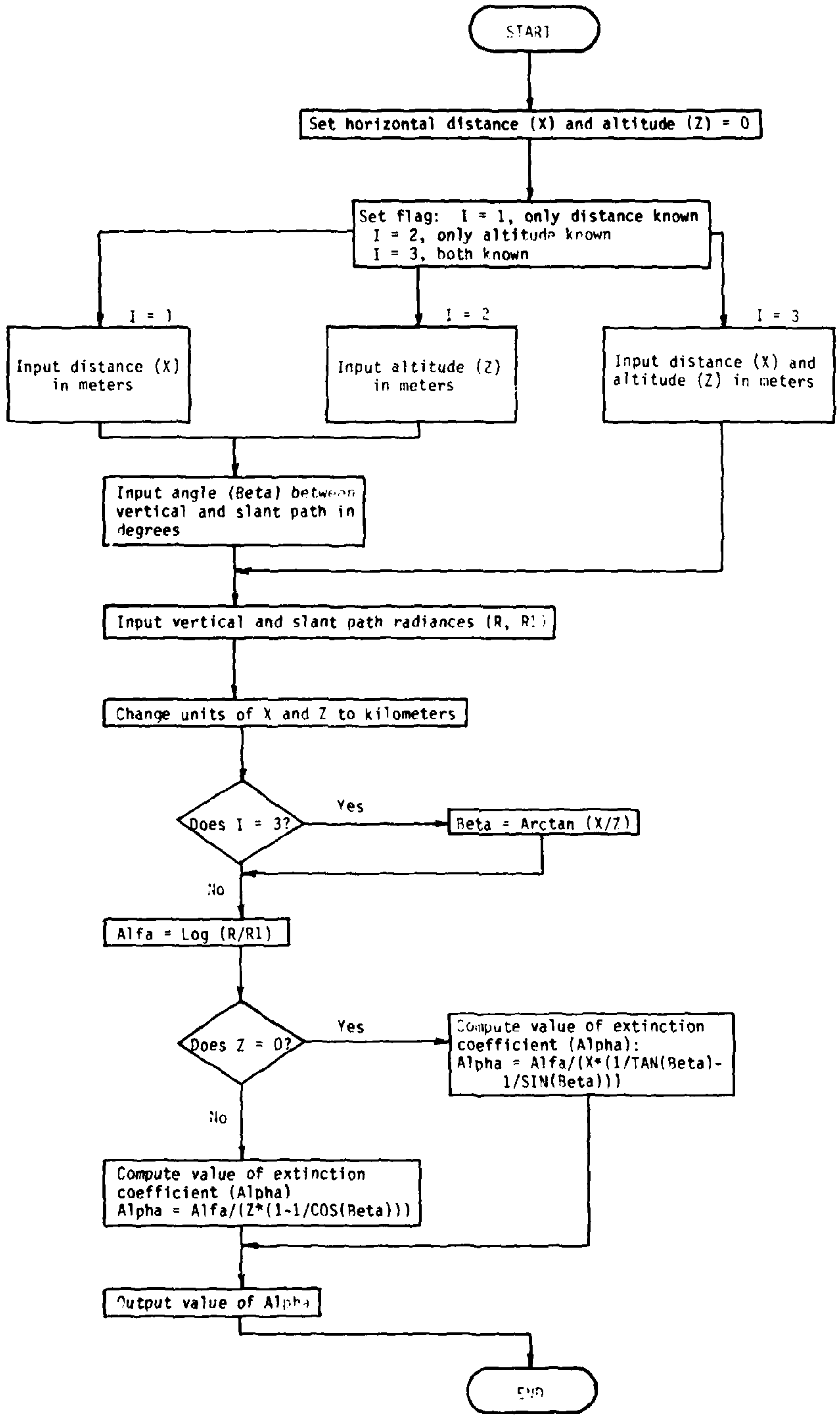

Figure 6. Flowchart of technique A for estimation of volume extinction coefficient.

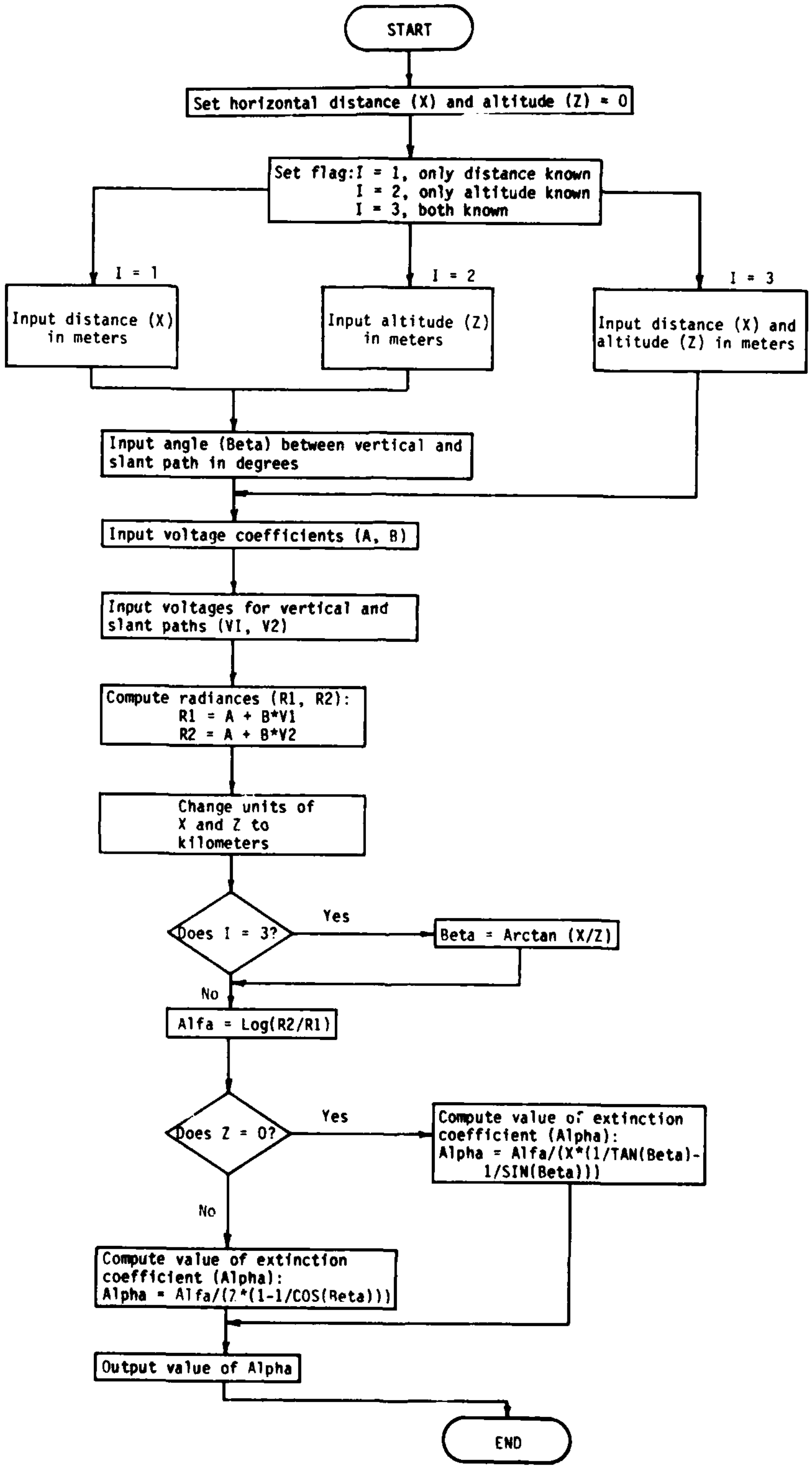

Figure 7. Flowchart of technique A for estimation of volume extinction coefficient using voltage input.

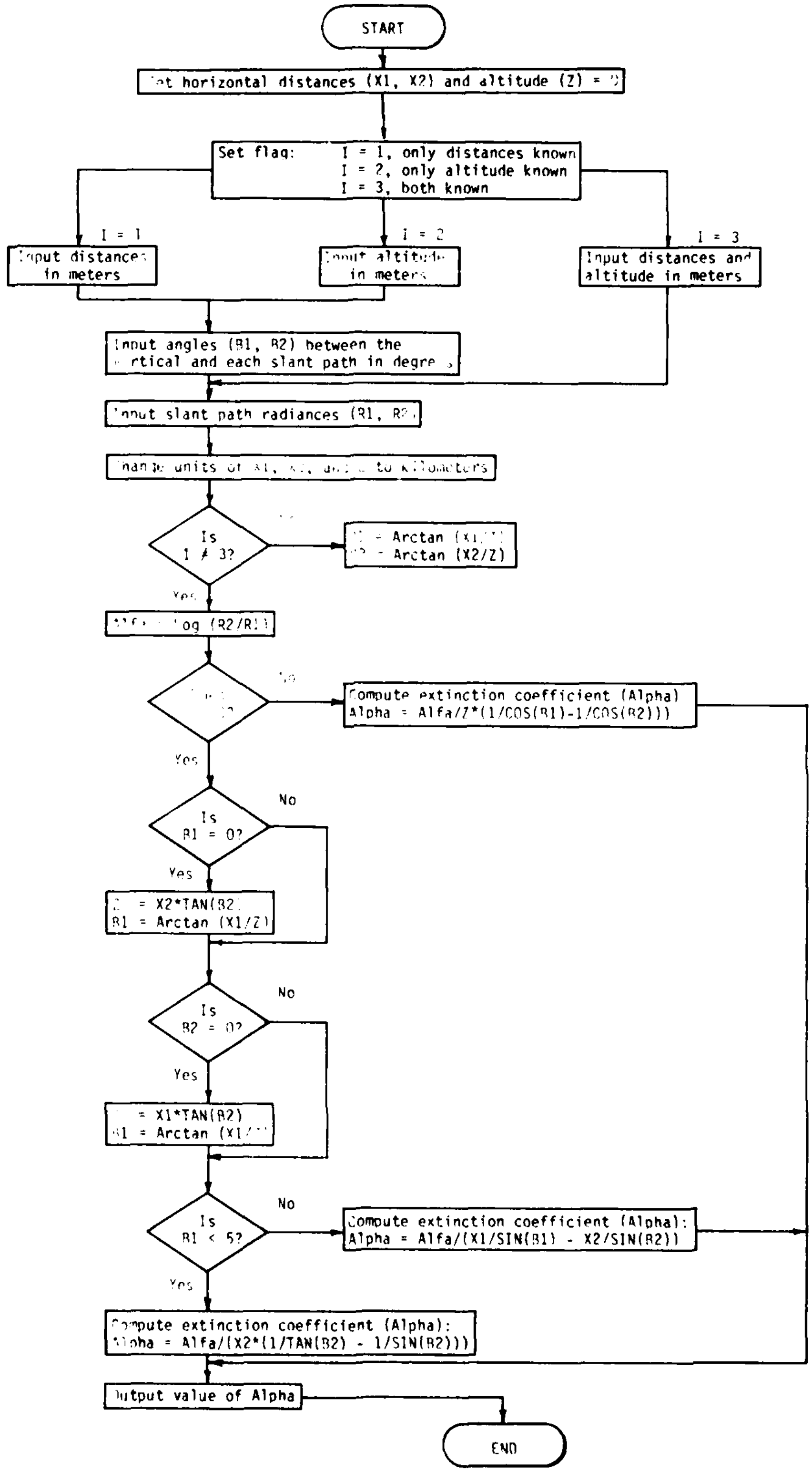

Figure 8. Flowchart of technique B for estimation of volume extinction coefficient.

In place of:

Input slant path radiances (R_1, R_2)

substitute:

Input voltage coefficients (A, B)

Input voltages for both slant paths (V_1, V_2)

Compute radiances (R_1, R_2):

$R_1 = A + B*V_1$

$R_2 = A + B*V_2$

Figure 9. Change in the flowchart (figure 8) for estimation of extinction coefficient with two slant paths when voltage input replaces radiance input.

Using equation (7) and substituting for X, we have for c

$$c = Z + Z \operatorname{ctn} \alpha \tan \beta$$

$$= Z\,(1 + \tan \beta/\tan \alpha)\ .$$

It has been assumed that the cloudbase can be observed directly above the landmark from the RPV (see figure 10). The computation of c becomes less accurate as the cloudbase to landmark path departs from vertical, although a departure of only a few degrees is not significant. Furthermore, it is assumed that the distance X is the same for both views, to the cloudbase and to the landmark. The value of c will depart from the real value as the difference in X for the two views. This problem could be solved if a side looking sensor was used or the RPV flew at a low speed and X was large. For example, relatively little degradation will occur if the speed of the RPV = 20 ms^{-1}, X = 4000 m, and the sensor viewed both scenes within 2 s.

The program for calculation of ceiling is presented as a "flowchart" in figure 11. The reader also should refer to figure 10 as an aid to understanding the flowchart. The computer code for this program is presented in the appendix.

3. SAMPLE COMPUTER RUNS

3.1 Wind Velocity

Four examples, two for each algorithm, are presented in this section to better demonstrate the computation of wind velocity by the two methods. For each example, a table shows the calculations required and an accompanying graph shows the graphical solution. Each set of one table and one graph is presented in the form of one figure for ease of understanding (figures 12 through 15). Although more than four situations exist (for example, "right" orientation for both C and D > 0 and both Dr_1 and Dr_2 known), to include them all for both methods would make this report unnecessarily large and tedious. Table 1 gives the computer output for these four examples.

Figures 12 and 13 present solutions for the first algorithm. In figure 12, C > 0 and D < 0, and the orientation is not known since only Dr_2 is given. Two solutions are computed, one of which is correct. Figure 13 has a "left" orientation where C < 0 and D > 0. Figure 2 and section 2.1.1 describe the relevant variables.

Figures 14 and 15 show solutions for the second algorithm. Figure 14 has an orientation that is "left" and C and D are negative. In figure 15, the orientation is unknown since only Dr_1 is known, and C and D are both positive. Figure 4 and section 2.1.2 describe the relevant variables.

3.2 Extinction Coefficient and Ceiling

A series of runs of the ceiling and the extinction coefficient (radiance input) programs were made to illustrate the algorithms. Sample output from the extinction programs that input voltage are not shown here because they essentially repeat the results of the radiance versions and a lengthy series of examples would be unnecessarily tedious. Tables 2 and 3 show computations for both techniques in which both manual and computer-generated values are

shown. Input values are listed with the appropriate equations. The radiance values have no specific units since they could have any standard (or nonstandard) units without affecting the results. In any case, the ratio of the radiances is dimensionless. Also, the values of k in these tables were computed for comparison and technique demonstration purposes, assuming perfect input. In the real world, the last two or three digits to the right of the decimal point probably would be meaningless.

Ceiling computations are shown in table 4 in a format similar to that of tables 2 and 3. Input values are listed along with the appropriate equations and both manual and computer-generated values are shown. Finally, table 5 presents samples of output from the computer programs used to generate the values in tables 2 through 4, and output from the "voltage" versions of the extinction programs.

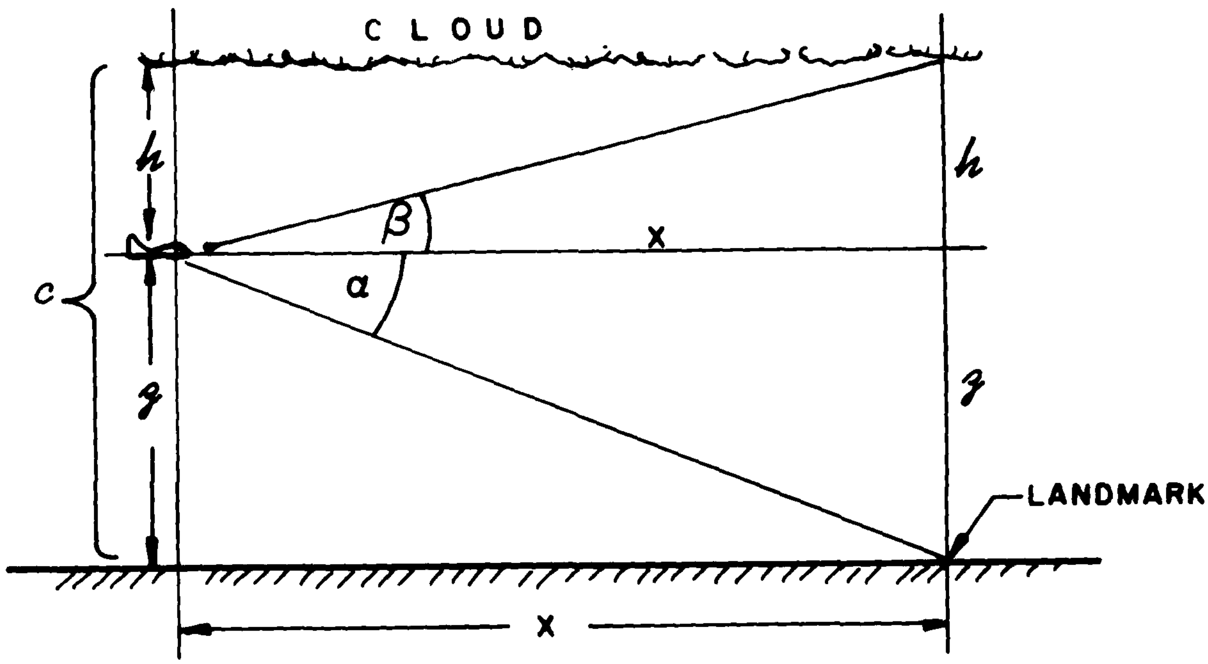

Figure 10. Geometry for estimation of ceiling (c = h + z) where z = altitude, h = height of cloudbase above flight level, x = ground distance, and α and β are angles relating z and h to x, respectively.

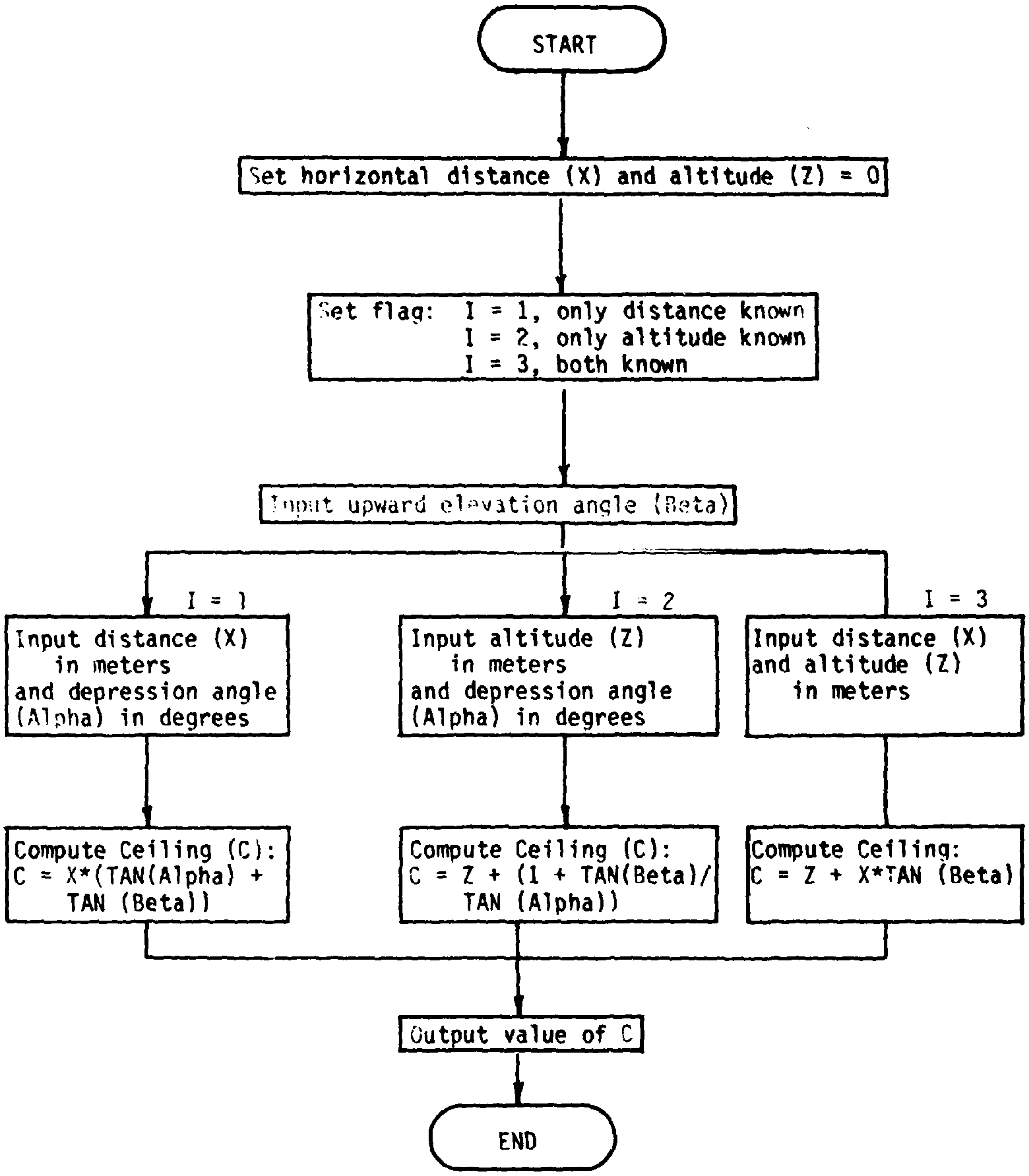

Figure 11. Flowchart for the estimation of ceiling.

$X = 75\ ms^{-1}$ $D_x = 3000\ m$ $T_x = 30\ s$ $Dr_1 = 999°$ (unknown)

$Y = 90\ ms^{-1}$ $D_y = 3000\ m$ $T_y = 50\ s$ $Dr_2 = 285°$

$X_g = D_x/T_x = 100\ ms^{-1}$ $Y_g = D_y/T_y = 60\ ms^{-1}$

$C = X_g - X = 25\ ms^{-1}$ $D = Y_g - Y = -30\ ms^{-1}$

$$V = (C^2 + D^2)^{1/2} = 39.1\ ms^{-1}$$

$P = \arctan |C/D| = 39.8°$ $Q = \arctan |D/C| = 50.2°$

$$Dr_1 = Dr_2 \pm 90° = 195° \text{ or } 375° - 360° = 15°$$

(1) $Dir = Dr_2 - P = 245.2°$

(2) $Dir = Dr_2 + P = 324.8°$

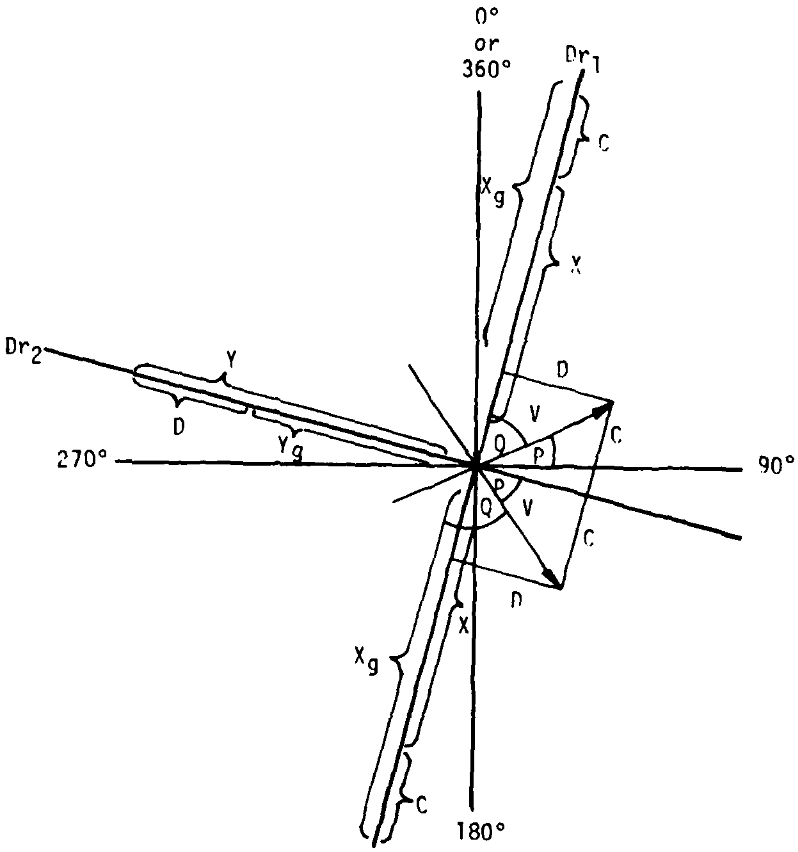

Figure 12. Use of method 1 to compute wind velocity. Variables are explained in figure 2 and first technique. Only Dr_2 is known, and $C > 0$ and $D < 0$. Two values of Dr_2, X, X_g, V, P, Q, C, and D are shown because Dr_1 may be 15° or 195°. Two wind velocities (V) are computed.

$X = 70\ ms^{-1}$ $\quad D_x = 4000$ m $\quad T_x = 68$ s $\quad Dr_1 = 345°$

$Y = 80\ ms^{-1}$ $\quad D_y = 5000$ m $\quad T_y = 60$ s $\quad Dr_2 = 255°$

$X_g = D_x/T_x = 58.8\ ms^{-1}$

$C = X_g - X = -11.2\ ms^{-1}$

$Y_g = D_y/T_y = 83.3\ ms^{-1}$

$D = Y_g - Y = 3.3\ ms^{-1}$

$$V = (C^2 + D^2)^{1/2} = 11.7\ ms^{-1}$$

$P = \arctan |C/D| = 73.6°$

$Q = \arctan |D/C| = 16.4°$

$$Dir = Dr_1 + Q = 345 + 16.4 = 361.4 = 361.4 - 360 = 1.4°$$

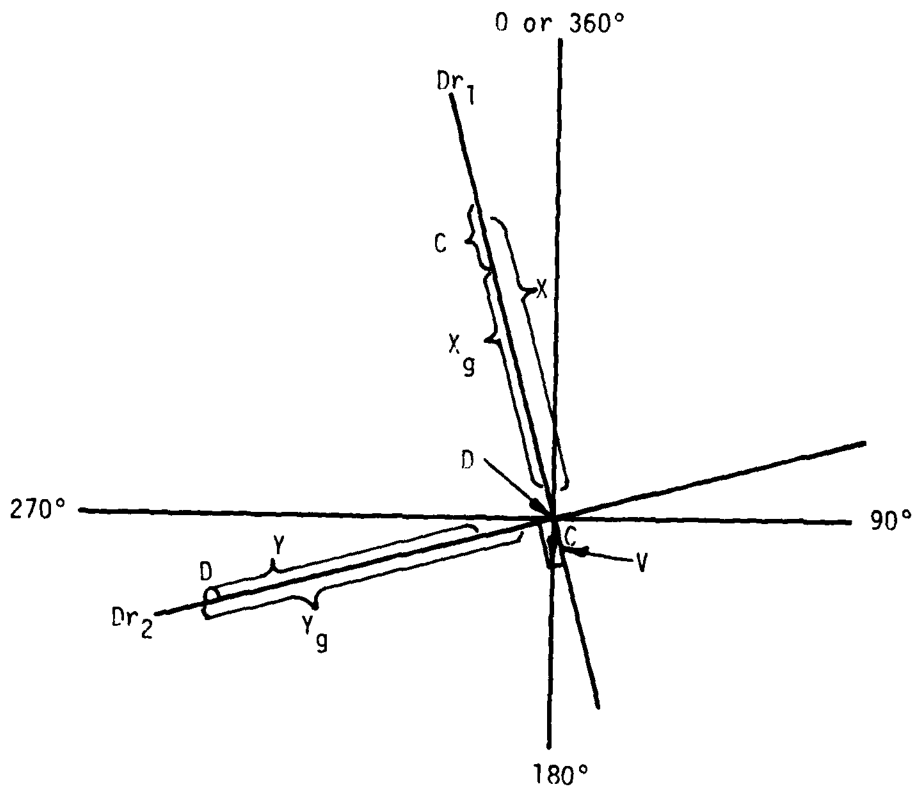

Figure 13. Use of method 1 to compute wind velocity when both Dr_1 and Dr_2 are known. Variables are explained in figure 2 and first technique. Here $C < 0$ and $D > 0$. The orientation of this figure is "left."

$X = 69\ ms^{-1}$ $\quad A = 3°$ $\quad Dr_1 = 90°$ $\quad I = -1$

$Y = 78\ ms^{-1}$ $\quad B = 10°$ $\quad Dr_2 = 360°$

$$A = I \times A = -3°$$
$$B = I \times B = -10°$$
$$C = X \tan A = -3.6\ ms^{-1}$$
$$D = Y \tan B = -13.8°\ ms^{-1}$$

$$V = (C^2 + D^2)^{1/2} = 14.3\ ms^{-1}$$

$$P = \arctan |C/D| = 14.6°$$
$$Q = \arctan |D/C| = 75.4°$$

$$Dir = Dr_1 + P = 104.6°$$

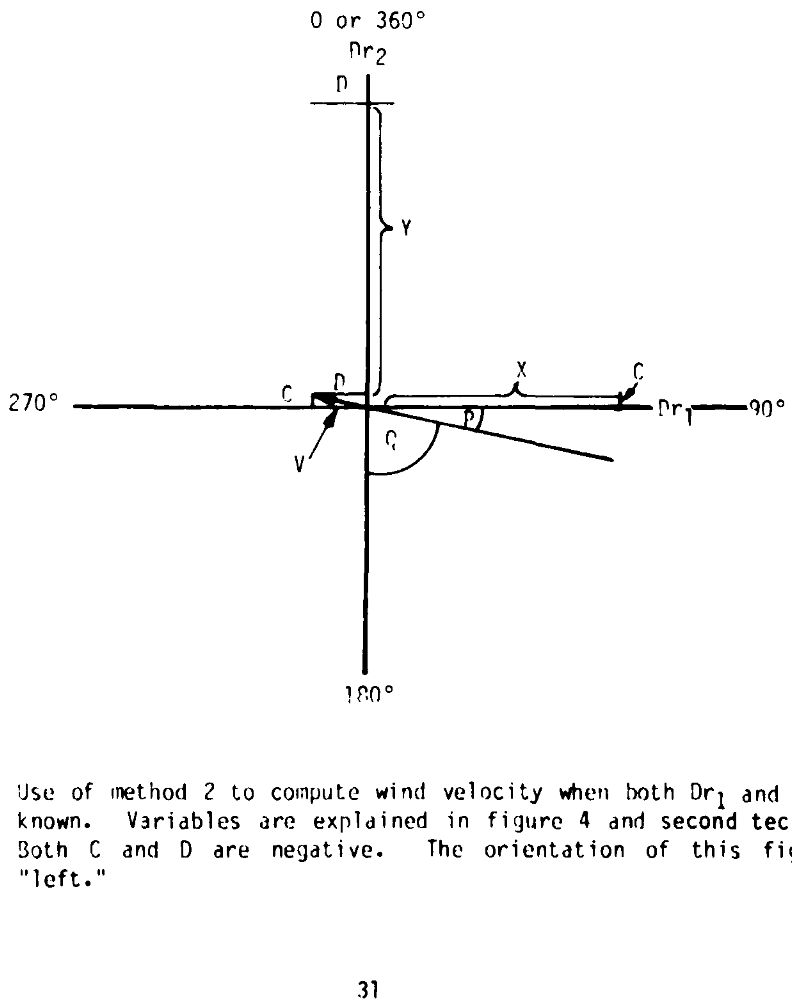

Figure 14. Use of method 2 to compute wind velocity when both Dr_1 and Dr_2 are known. Variables are explained in figure 4 and second technique. Both C and D are negative. The orientation of this figure is "left."

$X = 50\ ms^{-1}$ $A = -15°$ $Dr_1 = 245°$ $I = -1$

$Y = 50\ ms^{-1}$ $B = -25°$ $Dr_2 = 999°$ (unknown)

$$A = I \times A = 15°$$
$$B = I \times B = 25°$$
$$C = X \tan A = 13.4\ ms^{-1}$$
$$D = Y \tan B = 23.3\ ms^{-1}$$

$$V = (C^2 + D^2)^{1/2} = 26.9\ ms^{-1}$$

$$P = \arctan |C/D| = 29.9°$$
$$Q = \arctan |D/C| = 60.1°$$
$$Dr_2 = Dr_1 \pm 90° = 335° \text{ or } 155°$$

(1) $Dir = Dr_1 - P = 215.1°$

(2) $Dir = Dr_1 + P + 180 = 454.9 - 360 = 94.9°$

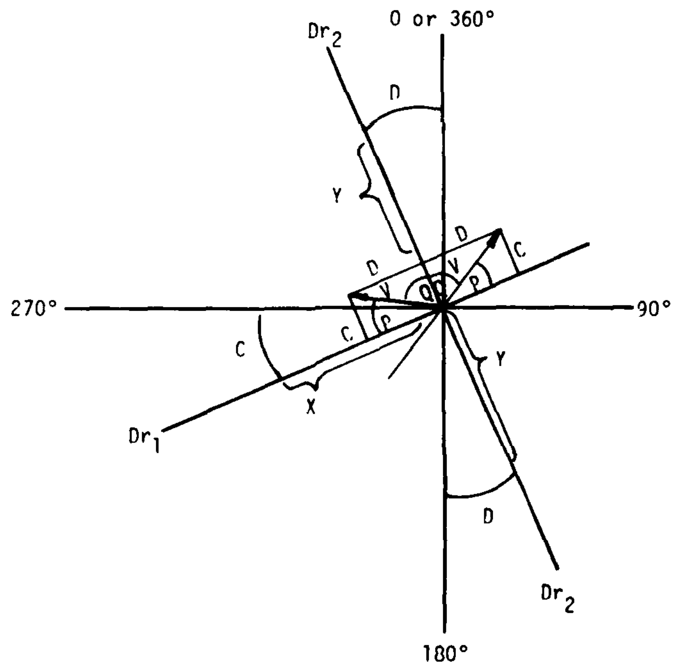

Figure 15. Use of method 2 to compute wind velocity. Variables are explained in figure 4 and second technique. Only Dr_1 is known, and C and D are both positive. More than one value of some variables is shown because Dr_2 may be 155° or 335°. Two wind velocities (V) are computed.

TABLE 1. COMPUTER OUTPUT FOR THE FOUR EXAMPLES OF FIGURES 12 THROUGH 15. AS NOTED IN THOSE FIGURES, TWO ANSWERS ARE GIVEN WHEN ONE HEADING IS UNKNOWN. THE MOST PROBABLE OF THE TWO WIND DIRECTIONS IS DETERMINED WITH THE AID OF OTHER DATA (FOR EXAMPLE, A SYNOPTIC CHART).

5 WIND VELOCITY

Windspeed = 39.1 ms^{-1}	Wind direction = 245.2°
Windspeed = 39.1 ms^{-1}	Wind direction = 324.8°

ONE ANSWER IS CORRECT

6 WIND VELOCITY

Windspeed = 11.7 ms^{-1}	Wind direction = 1.6°

7 WIND VELOCITY

Windspeed = 14.2 ms^{-1}	Wind direction = 104.7°

8 WIND VELOCITY

Windspeed = 26.9 ms^{-1}	Wind direction = 215.1°
Windspeed = 26.9 ms^{-1}	Wind direction = 94.9

ONE ANSWER IS CORRECT

TABLE 2. SAMPLE COMPUTATIONS OF VOLUME EXTINCTION COEFFICIENT USING TECHNIQUE A WITH RADIANCE INPUT. k = VOLUME EXTINCTION COEFFICIENT, X = HORIZONTAL DISTANCE, Z = ALTITUDE, β = ANGLE BETWEEN VERTICAL AND LOS TO TARGET, AND R AND R_1 = RADIANCES FROM THE TARGET WITH VERTICAL AND SLANT VIEWING, RESPECTIVELY. FOR THESE EXAMPLES R = 100 AND R_1 = 25 UNITS; THEREFORE, $R_1/R = 0.25$ and $\ln (R_1/R) = -1.3863$. NOTE THAT HERE AND IN THE COMPUTER PROGRAMS $R_1 = R_2$ OF EQUATION (3) AND $R = R_1$ OF EQUATION (3).

	Known Variables	Equations and "Manual" Values	Computer Values
a)	X = 1000 m = 1.0 km	$\beta = \arctan (X/Z)$	
	Z = 200 m = 0.2 km	$= 78.69°$	
		$k = \ln R_1/R/Z(1 - 1/\cos \beta)$	
		$= -1.3863/0.2(1 - 5.0990)$	
		$= 1.6910\ km^{-1}$	$1.6910\ km^{-1}$
b)	Z = 300 m = 0.3 km	$k = -1.3863/Z(1 - 1/\cos \beta)$	
	β = 65°	$= -1.3863/0.3(1 - 2.3662)$	
		$= 3.3824\ km^{-1}$	$3.3824\ km^{-1}$
c)	X = 600 m = 0.6 km	$k = -1.3863/X(1/\tan \beta - 1/\sin \beta)$	
	β = 50°	$= -1.3863/0.6(0.8391 - 1.3054)$	
		$= 4.9550\ km^{-1}$	$4.9549\ km^{-1}$

TABLE 3. SAMPLE COMPUTATIONS OF VOLUME EXTINCTION COEFFICIENT USING TECHNIQUE B WITH RADIANCE INPUT. k = VOLUME EXTINCTION COEFFICIENT, X_1 AND X_2 = HORIZONTAL DISTANCE, Z = ALTITUDE, β_1 AND β_2 = ANGLES BETWEEN VERTICAL AND LOS TO TARGET, AND R_1 AND R_2 = RADIANCE FROM THE TARGET ALONG THE TWO SLANT PATHS. FOR THESE EXAMPLES, R_1 = 100 AND R_2 = 30 UNITS; THEREFORE, $R_2/R_1 = 0.30$ AND $\ln (R_1/R_2) = -1.2040$.

Known Variables	Equations and "Manual" Values	Computer Values
a) X_1 = 300 m = 0.3 km	β_1 = arctangent (X_1/Z) = 30.96°	
X_2 = 1500 m = 0.5 km	β_2 = arctangent (X_2/Z) = 71.57°	
Z = 500 m = 0.5 km		
	$k = \ln (R_2/R_1)/Z(1/\cos \beta_1 - 1/\cos \beta_2)$	
	= -1.2040/0.5(1.661 - 3.1631)	
	= 1.2058 km^{-1}	1.2063 km^{-1}
b) Z = 500 m = 0.5 km	k = -1.2040/0.5(1.0642 - 2.9238)	
β_1 = 20°	= 1.2949 km^{-1}	1.2949 km^{-1}
β_2 = 70°		
c) X_1 = 200 m = 0.2 km	$k = 1.2040/(X_1/\sin \beta_1 - X_2/\sin \beta_2)$	
X_2 = 2000 m = 2.0 km	= -1.2040/(0.7727 - 2.1347)	
β_1 = 15°	= 0.8840 km^{-1}	0.8839 km^{-1}
β_2 = 69.53°		
d) X_1 = 40 m = 0.04 km	$k = -1.2040/X_2(1/\tan \beta_2 - 1/\sin \beta_2)$	
X_2 = 1500 m = 1.5 km	= -1.2040/1.5(0.5089 - 1.1220)	
β_1 = 3°	= 1.3091 km^{-1}	1.3090 km^{-1}
β_2 = 63.03°		

TABLE 4. SAMPLE COMPUTATION OF CEILING. c = CEILING (HEIGHT OF CLOUDBASE), Z = ALTITUDE, h = HEIGHT OF CLOUDBASE ABOVE FLIGHT PATH, X = HORIZONTAL DISTANCE, β = UPWARD ELEVATION ANGLE BETWEEN FLIGHT PATH AND LOS TO CLOUDBASE, AND α = DEPRESSION ANGLE BETWEEN FLIGHT PATH AND LOS TO LANDMARK (VERTICALLY BELOW VIEW OF CLOUDBASE). COMPUTED VALUES OF c ARE TO THE NEAREST METER.

Known Variables	Equations and "Manual" Values	Computer Values
a) X = 700 m	$c = Z + X\tan \beta$	
Z = 150 m	= 150 + 283	
β = 22°	= 433 m	433 m
b) Z = 300 m	$c = Z (1 + \tan \beta/\tan \alpha)$	
β = 14°	= 300(1 + 0.24933/0.17633)	
α = 10°	= 724 m	724 m
c) X = 1000 m	$c = X(\tan \alpha + \tan \beta)$	
β = 20°	= 1000(0.57735 + 0.36397)	
α = 30°	= 941 m	941 m

TABLE 5. SAMPLES OF OUTPUT FROM THE COMPUTER PROGRAMS FOR CEILING AND VOLUME EXTINCTION COEFFICIENT. ONLY THE ANSWER (FOR EXAMPLE, Ceiling = 100 m) IS PRINTED BY THE COMPUTER. SINCE THE DESKTOP COMPUTER CANNOT PRINT SUPERSCRIPTS, km^{-1} IS PRINTED AS 1/km.

1. Ceiling given altitude (Z) = 150 m, horizontal distance (X) = 700 m, and elevation angle (θ) = 22°.

   Ceiling = 433 m

2. Volume extinction coefficient using one slant path given Z = 200 m, X = 450 m, and radiances (R and R_1) = 110 and 25 units.

   Volume extinction coefficient = 5.0663 1/km

3. Volume extinction coefficient using two slant paths given horizontal distances (X_1 and X_2) = 200 and 1800 m, one of the two angles between the LOS to the target and the vertical (β_1) = 18°, and radiances (R_1 and R_2) = 100 and 20 units.

   Volume extinction coefficient = 1.2823 1/km

4. Volume extinction coefficient using one slant path, and using voltages as input given Z = 200 m, X = 450 m, voltage coefficients (A and B) = 2.2 and 11.0, and voltages (V_1 and V_2) = 8.0 and 2.0 v.

   Volume extinction coefficient = 4.4989 1/km

5. Volume extinction coefficient using two slant paths, and using voltages as input given Z = 200 m, X_1 and X_2 = 200 and 450 m, β_1 = 45°, A and B = 2.2 and 11.0, and V_1 and V_2 = 8.0 and 2.0 v.

   Volume extinction coefficient = 6.2771 1/km

4. CONCLUSION

Useful tools for silent area analysis have been developed in the form of simple methods for the computation of wind velocity, ceiling, and volume extinction coefficient. These algorithms use information already gathered by an RPV of the type being developed for the Army; no new instrumentation is required. Windspeed should be accurate to several tenths of a meter per second and wind direction to less than a degree, assuming that the input is "perfectly" accurate. Similarly, ceiling should be correct to about 1 or 2 percent and extinction coefficient to about 10 percent. However, under operational conditions, the accuracy of the input data probably would determine the accuracy of the output.

Computations may be performed via a desktop computer able to use the BASIC computer language, or by the use of a hand-held calculator, a fine-scaled ruler, and graph paper. The former technique only requires the operator to input numbers that are specifically requested; the latter manual technique requires some knowledge of the situation.

APPENDIX

COMPUTER CODES IN BASIC FOR THE RPV PROGRAMS

(A) is the full version and (B) is the shortened version of the wind velocity program; (C) is the ceiling program; (D) and (E) are the extinction coefficient programs with one and two slant paths, respectively; (F) and (G) are the extinction coefficient programs using voltage inputs, with one and two slant paths, respectively.

(A)

```
10 !
20 ! COMPUTE WIND VELOCITY USING RPV PROGRAM
30 !
40  A$="Wind Speed = "
50  B$="Wind Direction = "
60  D$=" m/s"
70  E$=" Degrees"
80  F$="WIND VELOCITY"
90   N=0
100  M=0
110  INPUT "Input L=1 to compute V using Method 1 or L=2 for Method 2",L
120  IF L=2 THEN GOTO Meth
130  INPUT "Input airspeeds in m/s (X and Y)",X,Y
140  INPUT "Input distances(m) and times(s) (Dx,Tx,Dy,Ty)",Dx,Tx,Dy,Ty
150  INPUT "Input headings in degrees (Dr1 and Dr2)",Dr1,Dr2
160  PRINT USING Heading;F$
170 Heading:  IMAGE 15X,13A,2/
180  GOTO Anda
190 Meth:  INPUT "Input airspeeds in m/s (X and Y)",X,Y
200  INPUT "Input whether drift (I=1) or correction (I=-1) angle",I
210  INPUT "Input angles in degrees (A and B)",A,B
220  INPUT "Input headings in degrees (Dr1 and Dr2)",Dr1,Dr2
230  A=I*A
240  B=I*B
250  PRINT USING Heading;F$
260  GOTO Otra
270 Anda:   CALL Comp1(X,Y,Dx,Tx,Dy,Ty,Dr1,Dr2,V,Dir,N)
280  GOTO Printer
290 Otra:   CALL Comp2(X,Y,A,B,Dr1,Dr2,U,V,Dir,I,M)
300 Printer:  PRINT USING Title;A$,V,D$,B$,Dir,E$
310 Title:   IMAGE 5X,13A,DDD.D,4A,5X,17A,DDD.D,8A,/
320  IF N=1 THEN GOTO Anda
330  IF M=1 THEN GOTO Otra
340  IF (N=2) OR (M=2) THEN PRINT "             ONE ANSWER IS CORRECT"
350  PRINT USING Out
360 Out: IMAGE 5X,6/
370  END
380  !
390  !
400  !   SUBPROGRAMS
410  !
420  !
430  SUB Comp1(X,Y,Dx,Tx,Dy,Ty,Dr1,Dr2,V,Dir,N)
440  !
450  Dir=0
460  DEG
470  L=0
480  Xg=Dx/Tx
490  Yg=Dy/Ty
500  C=Xg-X
510  D=Yg-Y
520  V=(C^2+D^2)^.5
530  IF C=0 THEN C=.001
540  IF D=0 THEN D=.001
550 !
560 !    Computation of Direction
570 !
580  P=ATN(ABS(C/D))
590  Q=ATN(ABS(D/C))
600  IF (C>0) AND (D>0) OR (C<0) AND (D<0) THEN L=1
610  Dron=Dr1
620  Drto=Dr2
630  IF Dr1=999 THEN GOTO Second              !  Is Dr1 missing?
640  IF Dr2=999 THEN Drto=Dr1+90              !  Is Dr2 missing?
650  IF (Dr2=999) AND (N=1) THEN Drto=Dr1-90
```

```
660   IF Drto<0 THEN Drto=Drto+360
670   IF Drto>360 THEN Drto=Drto-360
680   IF (Dron<=90) AND (Drto>=270) AND (Drto<=360) THEN Dron=Dron+360
690   IF (Drto<=90) AND (Dron>=270) AND (Dron<=360) THEN Drto=Drto+360
700   Dir=Dr1-Q                                  !  Headwind
710   IF (Drto<Dron) AND (L=0) THEN Dir=Dr1+Q
720   IF (Drto>Dron) AND (L=1) THEN Dir=Dr1+Q
730   IF C>0 THEN Dir=Dir+180                    !  Tailwind
740   GOTO Direct
750 Second: IF Dr2=999 THEN GOTO Alt             !  Are Dr1 & Dr2 missing?
760   Dron=Dr2+90                                !  Only Dr1 is missing
770   IF N=1 THEN Dron=Dr2-90
780   IF Dron<0 THEN Dron=Dron+360
790   IF Dron>360 THEN Dron=Dron-360
800   IF (Dron<=90) AND (Drto>=270) AND (Drto<=360) THEN Dron=Dron+360
810   IF (Drto<=90) AND (Dron>=270) AND (Dron<=360) THEN Drto=Drto+360
820   Dir=Dr2+P                                  !  Headwind
830   IF (Drto<Dron) AND (L=0) THEN Dir=Dr2-P
840   IF (Drto>Dron) AND (L=1) THEN Dir=Dr2-P
850   IF D>0 THEN Dir=Dir+180                    !  Tailwind
860   GOTO Direct
870 Alt: PRINT "NO DIRECTION GIVEN OR COMPUTED"
880 Direct:   IF Dir>360 THEN Dir=Dir-360
890   IF Dir<0 THEN Dir=Dir+360
900   IF (Dr1=999) OR (Dr2=999) THEN N=N+1
910   SUBEND
920   !
930   !
940   SUB Comp2(X,Y,A,B,Dr1,Dr2,U,V,Dir,I,M)
950   !
960   Dir=0
970   K=0
980   U=0
990   DEG
1000  C=X*TAN(A)
1010  D=Y*TAN(B)
1020  V=(C^2+D^2)^.5
1030  IF C=0 THEN C=.001
1040  IF D=0 THEN D=.001
1050 !
1060 !   Computation of Direction
1070 !
1080  P=ATN(ABS(C/D))
1090  Q=ATN(ABS(D/C))
1100  IF (C>0) AND (D>0) OR (C<0) AND (D<0) THEN K=1
1110  Dron=Dr1
1120  Drto=Dr2
1130  IF Dr1=999 THEN GOTO Second                 !  Is Dr1 missing?
1140  IF Dr2=999 THEN Drto=Dr1+90                 !  Is Dr2 missing?
1150  IF (Dr2=999) AND (M=1) THEN Drto=Dr1-90
1160  IF Drto<0 THEN Drto=Drto+360
1170  IF Drto>360 THEN Drto=Drto-360
1180  IF (Dron<=90) AND (Drto>=270) AND (Drto<=360) THEN Dron=Dron+360
1190  IF (Drto<=90) AND (Dron>=270) AND (Dron<=360) THEN Drto=Drto+360
1200  IF (D>0) AND (Dron>Drto) THEN U=1           !  Test for tailwind
1210  IF (D<0) AND (Dron<Drto) THEN U=1           !  Test for tailwind
1220  Dir=Dr1-P                                   !  Headwind
1230  IF (Dron>Drto) AND (K=1) THEN Dir=Dr1+P
1240  IF (Dron<Drto) AND (K=0) THEN Dir=Dr1+P
1250  IF U=1 THEN Dir=Dir+180                     !  Tailwind
1260  GOTO Direct
1270 Second:  IF Dr2=999 THEN GOTO Alt           !  Are Dr1 & Dr2 missing?
1280  Dron=Dr2+90                                 !  Only Dr1 is missing
1290  IF M=1 THEN Dron=Dr2-90
1300  IF Dron<0 THEN Dron=Dron+360
1310  IF Dron>360 THEN Dron=Dron-360
```

```
1320  IF (Dron>=90) AND (Drto<=270) AND (Drto>Dr[illegible]  [illegible]
1330  IF (Drto<=90) AND (Dron>=270) AND (Dron<=360) THEN [illegible]
1340  IF (C<0) AND (Dron>Drto) THEN U=1             !  Test for tailwind
1350  IF (C>0) AND (Dron<Drto) THEN U=1             !  Test for tailwind
1360  Dir=Dr2+Q                                     !  Headwind
1370  IF (Dron>Drto) AND (K=1) THEN Dir=Dr2-Q
1380  IF (Dron<Drto) AND (K=0) THEN Dir=Dr2-Q
1390  IF U=1 THEN Dir=Dir+180                       !  Tailwind
1400  GOTO Direct
1410 Alt:  PRINT "NO DIRECTION GIVEN OR COMPUTED"
1420 Direct:  IF Dir>360 THEN Dir=Dir-360
1430  IF Dir<0 THEN Dir=Dir+360
1440  IF (Dr1=999) OR (Dr2=999) THEN M=M+1
1450  SUBEND
```

B

```
10 !
20 ! COMPUTE WIND VELOCITY USING RPV PROGRAM - MINI VERSION
30 !
40   A$="Wind Speed = "
50   B$="Wind Direction = "
60   D$=" m/s"
70   E$=" Degrees"
80   F$="WIND VELOCITY"
90    INPUT "Input L=1 to compute V using Method 1 or L=2 for Method 2",L
100   IF L=2 THEN GOTO Meth
110   INPUT "Input airspeeds in m/s (X and Y)",X,Y
120   INPUT "Input distances(m) and times(s) (Dx,Tx,Dy,Ty)",Dx,Tx,Dy,Ty
130   INPUT "Input headings in degrees (Dr1 and Dr2)",Dr1,Dr2
140   PRINT USING Heading;F$
150 Heading:  IMAGE 15X,13A,2/
160   GOTO Anda
170 Meth:  INPUT "Input airspeeds in m/s (X and Y)",X,Y
180   INPUT "Input whether drift (I=1) or correction (I=-1) angle",I
190   INPUT "Input angles in degrees (A and B)",A,B
200   INPUT "Input headings in degrees (Dr1 and Dr2)",Dr1,Dr2
210   A=I*A
220   B=I*B
230   PRINT USING Heading;F$
240   GOTO Otra
250 Anda:   CALL Comp1(X,Y,Dx,Tx,Dy,Ty,Dr1,Dr2,V,Dir)
260   GOTO Printer
270 Otra:   CALL Comp2(X,Y,A,B,Dr1,Dr2,U,V,Dir,I)
280 Printer:  PRINT USING Title;A$,V,D$,B$,Dir,E$
290 Title:   IMAGE 5X,13A,DDD.D,4A,5X,17A,DDD.D,8A,/
300   PRINT USING Out
310 Out: IMAGE 5X,6/
320   END
330   !
340   !
350   !   SUBPROGRAMS
360   !
370   !
380   SUB Comp1(X,Y,Dx,Tx,Dy,Ty,Dr1,Dr2,V,Dir)
390   !
400   Dir=0
410   DEG
420   L=0
430   Xg=Dx/Tx
440   Yg=Dy/Ty
450   C=Xg-X
460   D=Yg-Y
470   V=(C^2+D^2)^.5
480   IF C=0 THEN C=.001
490   IF D=0 THEN D=.001
500 !
510 !    Computation of Direction
520 !
530   Q=ATN(ABS(D/C))
540   IF (C>0) AND (D>0) OR (C<0) AND (D<0) THEN L=1
550   Dron=Dr1
560   Drto=Dr2
570   IF (Dron<=90) AND (Drto>=270) AND (Drto<=360) THEN Dron=Dron+360
580   IF (Drto<=90) AND (Dron>=270) AND (Dron<=360) THEN Drto=Drto+360
590   Dir=Dr1-Q                               !  Headwind
600   IF (Drto<Dron) AND (L=0) THEN Dir=Dr1+Q
610   IF (Drto>Dron) AND (L=1) THEN Dir=Dr1+Q
620   IF C>0 THEN Dir=Dir+180                 !  Tailwind
630   IF Dir>360 THEN Dir=Dir-360
640   IF Dir<0 THEN Dir=Dir+360
650   SUBEND
```

```
660    !
670    !
680    SUB Comp2(X,Y,A,B,Dr1,Dr2.U,V,Dir,I)
690    !
700    Dir=0
710    K=0
720    U=0
730    DEG
740    C=X*TAN(A)
750    D=Y*TAN(B)
760    V=(C^2+D^2)^.5
770    IF C=0 THEN C=.001
780    IF D=0 THEN D=.001
790 !
800 !     Computation of Direction
810 !
820    P=ATN(ABS(C/D))
830    IF (C>0) AND (D>0) OR (C<0) AND (D<0) THEN K=1
840    Dron=Dr1
850    Drto=Dr2
860    IF (Dron<=90) AND (Drto>=270) AND (Drto<=360) THEN Dron=Dron+360
870    IF (Drto<=90) AND (Dron>=270) AND (Dron<=360) THEN Drto=Drto+360
880    IF (D>0) AND (Dron>Drto) THEN U=1           !  Test for tailwind
890    IF (D<0) AND (Dron<Drto) THEN U=1           !  Test for tailwind
900    Dir=Dr1-P                                   !  Headwind
910    IF (Dron>Drto) AND (K=1) THEN Dir=Dr1+P
920    IF (Dron<Drto) AND (K=0) THEN Dir=Dr1+P
930    IF U=1 THEN Dir=Dir+180                     !  Tailwind
940    IF Dir>360 THEN Dir=Dir-360
950    IF Dir<0 THEN Dir=Dir+360
960    SUBEND
```

(C)

```
10   !
20   !     ESTIMATION OF CEILING   (STORED AS "RAVCEL")
30   !
40   !     INPUT
50   !
60   DEG
70   DATA  0,0
80   READ X,Z
90   A$="Ceiling = "
100  B$=" meters"
110  INPUT "Set I=1 if distance known, I=2 if altitude known, I=3 if both known"
,I
120  INPUT "Input upward elevation angle (Beta) in degrees",Beta
130  ON I GOTO In1,In2,In3
140 In1: INPUT "Input distance (X) in meters & depression angle (Alpha) in degre
es",X,Alpha
150  GOTO Comp1
160 In2: INPUT "Input altitude (Z) in meters & depression angle (Alpha) in degre
es",Z,Alpha
170  GOTO Comp2
180 In3: INPUT "Input distance (X) & altitude (Z) in meters",X,Z
190  GOTO Comp3
200 Comp1: C=X*(TAN(Alpha)+TAN(Beta))
210  GOTO Out
220 Comp2: C=Z*(1+TAN(Beta)/TAN(Alpha))
230  GOTO Out
240 Comp3: C=Z+X*TAN(Beta)
250 Out:   PRINT USING Title;A$,C,B$
260 Title: IMAGE @,5X,10A,5D.7A,//
270  END
```

D

```
10   !
20   !      ESTIMATION OF EXTINCTION COEFFICIENT    (STORED AS "RP\RAD")
30   !
40   !      INPUT
50   !
60   DATA  0,0
70   READ X,Z
80   INPUT "Set I=1 if distance known, I=2 if altitude known, I=3 if both known"
,I
90   ON I GOTO In1,In2,In3
100 In1:  INPUT "Input value of distance (X) in meters",X
110  GOTO Angle
120 In2:  INPUT "Input value of altitude (Z) in meters",Z
130  GOTO Angle
140 In3:  INPUT "Input distance (X) and altitude (Z) in meters",X,Z
150  GOTO In
160 Angle:   INPUT "Input angle (Beta) between vertical and slant paths in degre
es",Beta
170 In:  INPUT "Input vertical and slant path radiances (R,R1 : R<R1) in any sta
ndard units",R,R1
180  !
190  !      COMPUTATION
200  !
210  DEG
220  DIM A$[32]
230  X=X/1000                              ! Change units to kilometers
240  Z=Z/1000                              !
250  A$="Volume extinction coefficient = "
260  B$="  1/km"
270  IF I=3 THEN Beta=ATN(X/Z)
280  Alpha=LOG(R1/R)
290  IF Z=0 THEN GOTO Dist
300  Alpha=Alpha/(Z*(1-1/COS(Beta)))
310  GOTO Out
320 Dist:   Alpha=Alpha/(X*(1/TAN(Beta)-1/SIN(Beta)))
330  !
340  !      OUTPUT
350  !
360 Out:   PRINT USING Title;A$,Alpha,B$
370 Title:   IMAGE  @,5X,32A,DD.DDDD,6A,/
380  END
```

(E)

```
10  !
20  !      ESTIMATION OF EXTINCTION COEFFICIENT      (STORED AS "RADREV")
30  !      USING TWO SLANT PATHS
40  !
50  !      INPUT
60  !
70  DATA  0,0,0
80  READ X1,X2,Z
90  INPUT "Set I=1 if distances known, I=2 if altitude known, I=3 if both known
",I
100  ON I GOTO In1,In2,In3
110 In1:  INPUT "Input values of distances (X1,X2 where X1<X2) in meters",X1,X2
120  GOTO Angle
130 In2:  INPUT "Input value of altitude (Z) in meters",Z
140  GOTO Angle
150 In3:  INPUT "Input distances (X1,X2 where X1<X2) and altitude (Z) in meters"
,X1,X2,Z
160  GOTO In
170 Angle:   INPUT "Input angles (B1,B2 where B1<B2) between vertical and slant
paths in degrees",B1,B2
180 In:  INPUT "Input slant path radiances (R1,R2 where R1>R2) in any standard u
nits",R1,R2
190  !
200  !       COMPUTATION
210  !
220  DEG
230  DIM A$[32]
240  X1=X1/1000                                !
250  X2=X2/1000                                ! Change units to kilometers
260  Z=Z/1000                                  !
270  A$="Volume extinction coefficient = "
280  B$="  1/km"
290  IF I<>3 THEN GOTO Alf
300  B1=ATN(X1/Z)
310  B2=ATN(X2/Z)
320 Alf:  Alpha=LOG(R2/R1)
330  IF Z=0 THEN GOTO Dist
340  Alpha=Alpha/(Z*(1/COS(B1)-1/COS(B2)))
350  GOTO Out
360 Dist:  IF B1<>0 THEN GOTO Bet
370  Z=X2/TAN(B2)
380  B1=ATN(X1/Z)
390 Bet:  IF B2<>0 THEN GOTO Go
400  Z=X1/TAN(B1)
410  B2=ATN(X2/Z)
420 Go:   IF B1<5 THEN GOTO Small
430  Alpha=Alpha/(X1/SIN(B1)-X2/SIN(B2))
440  GOTO Out
450 Small:  Alpha=Alpha/(X2*(1/TAN(B2)-1/SIN(B2)))
460  !
470  !       OUTPUT
480  !
490 Out:   PRINT USING Title:A$,Alpha,B$
500 Title:   IMAGE @,5X,32A,DD.DDDD,6A,//
510  END
```

(F)

```
10   !
20   !      ESTIMATION OF EXTINCTION COEFFICIENT    (STORED AS "RPVOLT")
30   !      USING VOLTAGES AS INPUT
40   !
50   !      INPUT
60   !
70   DATA  0,0
80   READ X,Z
90   INPUT "Set I=1 if distance known, I=2 if altitude known, I=3 if both known"
,I
100  ON I GOTO In1,In2,In3
110 In1:  INPUT "Input value of distance (X) in meters",X
120  GOTO Angle
130 In2:  INPUT "Input value of altitude (Z) in meters",Z
140  GOTO Angle
150 In3:  INPUT "Input distance (X) and altitude (Z) in meters",X,Z
160  GOTO In
170 Angle:   INPUT "Input angle (Beta) between vertical and slant paths in degre
es",Beta
180 In:  CALL Volt(R1,R2,V1,V2,A,B)
190  !
200  !       COMPUTATION
210  !
220  DEG
230  DIM A$[32]
240  X=X/1000                              ! Change units to kilometers
250  Z=Z/1000                              !
260  A$="Volume extinction coefficient = "
270  B$="  1/km"
280  IF I=3 THEN Beta=ATN(X/Z)
290  Alpha=LOG(R2/R1)
300  IF Z=0 THEN GOTO Dist
310  Alpha=Alpha/(Z*(1-1/COS(Beta)))
320  GOTO Out
330 Dist:    Alpha=Alpha/(X*(1/TAN(Beta)-1/SIN(Beta)))
340  !
350  !       OUTPUT
360  !
370 Out:   PRINT USING Title;A$,Alpha,B$
380 Title:   IMAGE  @,5X,32A,DD.DDDD,6A,/,/
390  END
400  !
410  !       SUBPROGRAM TO CONVERT VOLTAGE TO RADIANCE
420  !
430  SUB Volt(R1,R2,V1,V2,A,B)
440  INPUT "Input voltage coefficients (A,B)",A,B
450  INPUT "Input voltages for vertical and slant paths (V1 V2 where V1>V2)",V1,
V2
460  R1=A+B*V1
470  R2=A+B*V2
480  SUBEND
```

(G)

```
[illegible] !
[illegible] !        ESTIMATION OF EXTINCTION COEFFICIENT [illegible]
[illegible] !        USING TWO SLANT PATHS AND VOLTAGES
[illegible] !        AS INPUT
[illegible] !
[illegible] !        INPUT
[illegible] !
[illegible]0   DATA  [illegible]
[illegible]0   READ X1,X2,Z
[illegible]    INPUT "Set I=1 if dist[illegible]" [illegible]
  I
[illegible]0   ON I GOTO In1,In2,In3
[illegible]0 In1:   INPUT "Input [illegible]"
[illegible]0   GOTO Angle
140 In2:   INPUT "Input value of alti[illegible]"
[illegible]0   GOTO Angle
[illegible]0 In3:   INPUT "Input distance[illegible] altitude[illegible]"
  [illegible]
[illegible]0   GOTO In
[illegible]0 Angle:      INPUT "Input [illegible]
paths in degrees",B1,B2
[illegible]0 In:   CALL Volt([illegible])
[illegible]   !
[illegible]10   !        COMPUTATION
[illegible]
[illegible]   DEG
[illegible]   DIM A$[3[illegible]]
[illegible]    [illegible]=[illegible]/1000
[illegible]    [illegible]2=[illegible]/1000
[illegible]    Z=Z/1000
[illegible]   A$="Volume extinction [illegible]"
[illegible]   [illegible]$="[illegible]/km"
[illegible]   IF I[illegible]3 THEN GOTO Alt
[illegible]   B1=ATN(X1/Z)
[illegible]   B2=ATN(X2/Z)
730 Alt:    Alpha=LOG(R2/R1)
[illegible]   IF Z=0 THEN GOTO Dist
[illegible]   Alpha=Alpha/(Z*[illegible]
750   GOTO Out
[illegible] Dist:     IF B1[illegible]0 THEN GOTO Bet
[illegible]   Z=X2/TAN(B2)
[illegible]   B1=ATN(X1/Z)
[illegible] Bet:     IF B2[illegible]0 THEN GOTO [illegible]
[illegible]   Z=X1/TAN(B1)
[illegible]   B2=ATN(X2/Z)
[illegible] Go:     IF B1[illegible]5 THEN GOTO Small
[illegible]   Alpha=Alpha/([illegible]/SIN(B1)-[illegible]/SIN([illegible]
[illegible]   GOTO Out
[illegible] Small:   Alpha=Alpha/([illegible]2*[illegible]TAN([illegible]
[illegible]   !
[illegible]0   !        OUTPUT
[illegible]   !
500 Out:    PRINT USING Title;A$,Alp[illegible]
[illegible] Title     IMAGE  [illegible]
[illegible]   END
[illegible]   !
[illegible]   !        SUBPROGRAM TO CONVERT VOLTAGE TO RA[illegible]
[illegible]   !
[illegible]   SUB Volt(R1,R2,V1,V2,A,B)
[illegible]   INPUT "Input voltage coefficient[illegible]",A,B
[illegible]   INPUT "Input voltages for both slant paths[illegible]"
[illegible]   R1=A+B*V1
[illegible]   R2=A+B*V2
[illegible]   SUBEND
```

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